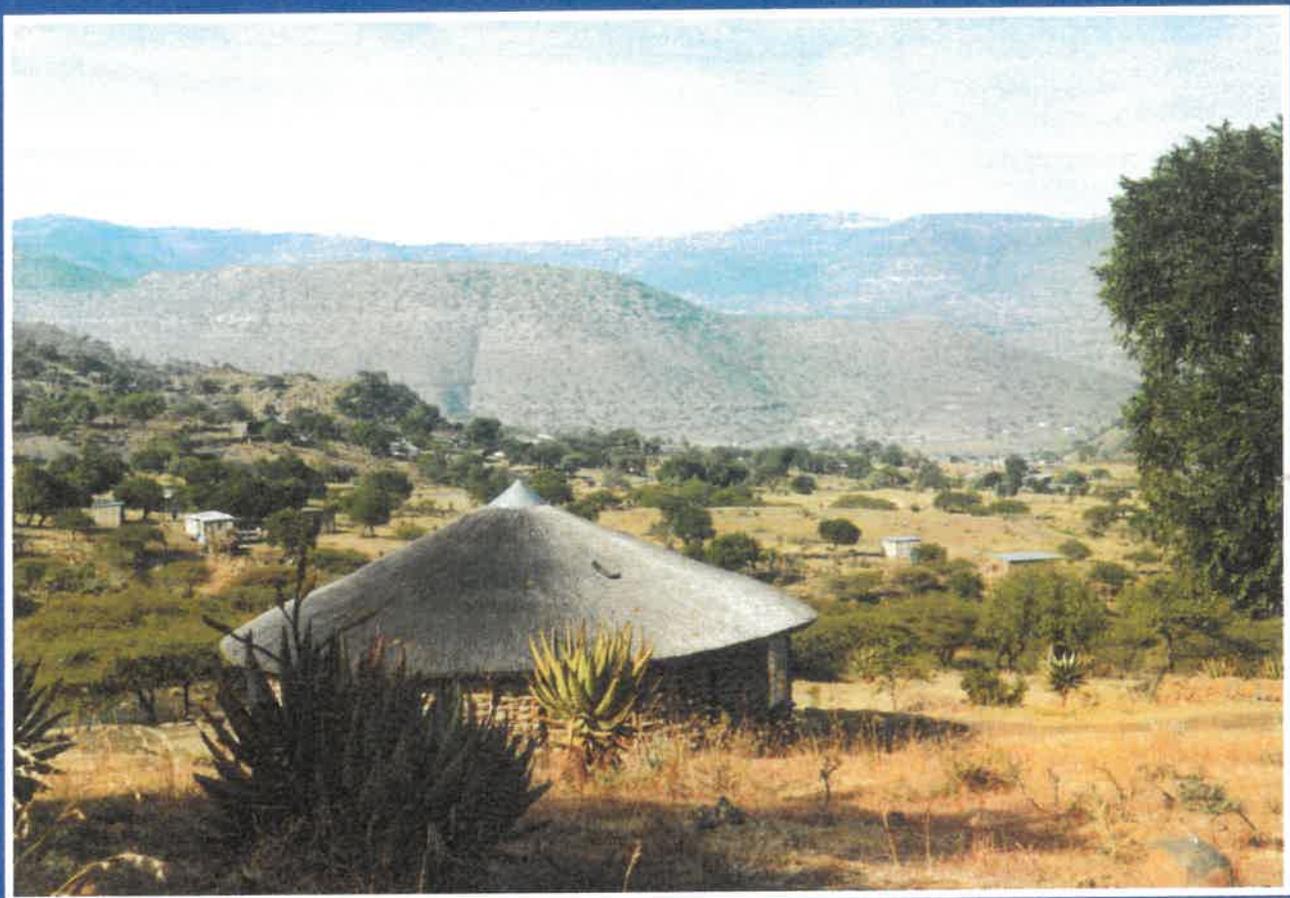


**An Explanation
of the 1:500 000
General Hydrogeological Map
Vryheid 2730**



**By G.M. King
April 2003**



DEPARTMENT : WATER AFFAIRS AND FORESTRY
REPUBLIC OF SOUTH AFRICA

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Cover photograph: A typical rural village in the Tugela River Valley. Numerous rural communities in the map area rely on groundwater for domestic use and for stock watering. (Photograph: P.S. Meyer).

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By G.M. King

April 2003

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DEPARTMENT: WATER AFFAIRS AND FORESTRY
REPUBLIC OF SOUTH AFRICA



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Foreword

Groundwater in South Africa as a whole is under-utilised, although some local over-exploitation does occur. Groundwater schemes can be implemented quickly and cheaply, and are particularly effective in conjunctive use and dispersed scenarios. With increasing pressure on scarce surface water resources, and with the priority of supplying potable water to disadvantaged rural and urban communities, it is clear that groundwater will play an increasingly important role in South Africa's economic and social prosperity.

A major obstacle to the realisation of this prosperity is that insufficient information about groundwater is reaching the planners, decision-makers, users and other affected parties. In an attempt to rectify this situation, groundwater information locked away in experts' minds and computer databases is being made available on maps. The first step in this programme at the regional level is the preparation of "Hydrogeological Maps" at the scale of 1:500 000.

The main purpose of Hydrogeological Maps, of which the accompanying map sheet is an example, is to display in an easily understood format what is known about the basic hydrogeology and hydrogeological rock properties. These Hydrogeological Maps represent a synthesis of the most up-to-date data and geohydrologists' knowledge. Thus these maps are also very useful in identifying areas where additional data should be collected and further investigations need to be conducted.

Groundwater maps – the best available information for the best possible planning, development and management of a strategic resource – will ultimately benefit all South Africans.

EBERHARD BRAUNE
DIRECTOR: GEOHYDROLOGY
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PRETORIA

Preface

Groundwater is rapidly growing in importance in South Africa but not enough information concerning this resource is reaching planners, decision-makers and users. Although groundwater is a reliable resource when properly managed, ignorance of its existence or character commonly results in it being used as a second option to more expensive and less reliable surface water schemes. In order to address the problem of a lack of groundwater knowledge, the Directorate: Geohydrology launched a regional mapping programme whereby South African groundwater resources will be portrayed at a scale of 1:500 000. The Vryheid map is one of twenty-three such maps to be produced.

This mapping exercise is intended to bring together all the information concerning the resource for analysis – thereby determining any regional scale variations in the groundwater characteristics. The findings are displayed on the map while more detailed information not readily portrayed on the map is given in this brochure.

The main theme displayed on the Hydrogeological Map series is the groundwater occurrence and flow regime. For example, aquifers in which flow is intergranular (usually unconsolidated material) are distinguished from aquifers in which flow is through fissures (fractures). In addition, the borehole productivity (dependent on rock permeability) is also ranked.

Settling on a legend for the South African 1:500 000 scale the Hydrogeological Map series entailed much debate and revision between 1991 and 1996, with inputs coming from parties within and outside Directorate: Geohydrology. The legend used is an adaptation of what is commonly known as the UNESCO legend – published jointly in 1983 by the IAH (International Association of Hydrogeologists), IAHS (International Association of Hydrological Sciences) and UNESCO (IAH, 1983).

Classification of fissured (fractured) groundwater occurrence is particularly important in the South African context because this type underlies at least 90% of the country. A modification to the UNESCO classification was considered necessary in order to incorporate a semi-quantitative expression of storage capacity of the rock interstices into the classification – distinguishing between “fractured” and “fractured and intergranular” groundwater occurrence. The latter is applicable where weathering has imparted intergranular properties to the residuum overlying the fractured bedrock. This weathered zone can provide significant groundwater storage, which can be transmitted to the underlying bedrock.

The South African approach to distinguish groundwater occurrence requires the identification and comparison of “hydrogeological units.” These being defined as “reasonably homogenous groundwater units which possess some degree of internal lithologic homogeneity and similarities in rock properties that impact on groundwater conditions and on groundwater quality” and are “described in terms of lithology, stratigraphy and a combination of mode of occurrence and typical yields of boreholes” (DWAF, 1994).

The groundwater occurrence classification adopted for the South African situation is thus as follows:

- Intergranular
- Fractured
- Karstic
- Fractured and Intergranular

A maximum of five productivity ranges could be accommodated – this is the maximum number of distinguishable shades of colour. The ranges accommodate yields for the country as a whole – based on an analysis of the yield frequency distribution of all the boreholes on the National Groundwater Data Base.

The Hydrogeological Map series gives an indication of where the groundwater resources are most accessible and the quality of the resources, but there is another important aspect – the volume of groundwater abstractable on a sustained basis. A first attempt at quantifying the resource at a regional scale is therefore included in this brochure. Areas most vulnerable to over-exploitation are also identified.

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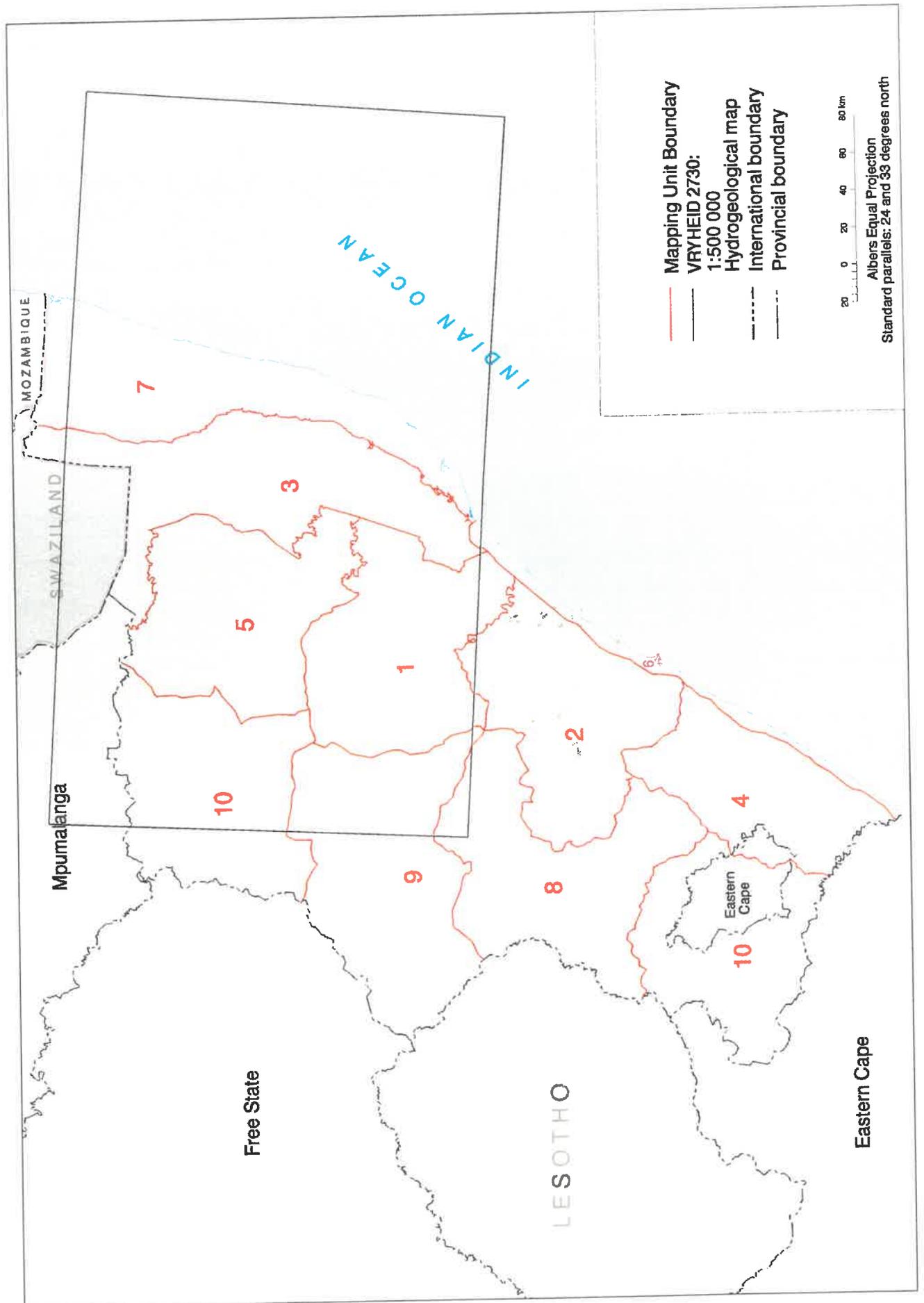
Abbreviations

CSIR	Council for Scientific and Industrial Research
DTH	Down the hole hammer
DWAF	Department: Water Affairs and Forestry
EC	Electrical conductivity
F	Fluoride
GIS	Geographic Information System
NGDB	National Groundwater Data Base
NWQDB	National Water Quality Data Base
NO ₃	Nitrate

Units

a	annum
ha	hectare
km	kilometre
km ²	square kilometre
l/s	litre per second
l/h	litre per hour
m	metre
m ³	cubic metre
m/day	metre per day
m ² /day	square metre per day
mg/l	milligram per litre
m ³ /km ² /a	cubic metre per square kilometre per annum
mm	millimetre
mS/m	milli-Siemens per metre
°C	degrees centigrade

Figure 1. KwaZulu-Natal Hydrogeological Mapping units



1 Introduction

1.1 Aims and objectives

The primary aim of the Vryheid Hydrogeological Map was to produce a synoptic overview of the hydrogeological character of the area by processing data according to a standard legend. The main features shown on the map are borehole yield, aquifer type, groundwater quality, groundwater use, and lithology.

This brochure was compiled to provide supplementary information on these features, and also to:

- determine the hydrogeological parameters to consider in siting boreholes,
- describe the hydrochemical character of the groundwater,
- make a preliminary estimate of maximum and optimum sustainable abstraction rates,
- facilitate the focus of future research directions by identifying knowledge gaps.

1.2 Previous hydrogeological investigations

1.2.1 KwaZulu-Natal Hydrogeological Characterisation and Mapping Project

KwaZulu-Natal has traditionally been considered a well-watered province with adequate surface water. Prior to 1980, groundwater was rarely considered an important natural resource and this resulted in neglect of its evaluation and management.

The severe droughts of 1982–83 and again of 1991–93 changed the perspective, water restrictions were imposed, and attention was diverted to groundwater as a possible alternative source of water. During these periods, both public and private organisations undertook major groundwater drilling and spring protection programmes in an attempt to alleviate the shortages of potable water, particularly in the rural areas. Much of the hydrogeological data generated by these projects were never formally collected and analysed.

In 1993, the Department: Water Affairs and Forestry (DWAF) together with the Water Research Commission, the KwaZulu Government, the Water Services Advisory Board, and the former Joint Services Boards of Port Natal-Ebhodwe, Midlands, Zululand, Southern Natal and East Griqualand, and Umgeni Water and Mhlathuze Water funded the KwaZulu-Natal Hydrogeological Characterisation and Mapping Project.

Due to a shortage of trained personnel within DWAF in KwaZulu-Natal and paucity of readily available groundwater and related data, it was decided to appoint a number of groundwater consultants with Directorate: Geohydrology in order to accelerate the project. The aim of this project was to expand the hydrogeological data base as contained in both the National Ground Water Data Base (NGDB) and the National

Water Quality Data Base (NWQDB) by the verification of existing NGDB borehole data, collection of new data and groundwater sampling. The final products of the project were eleven 1:250 000 scale hydrogeological maps and accompanying brochures characterising the groundwater resources and depicting its occurrence, recharge potential and ambient quality. The distribution of Mapping Units covered by the Vryheid 1:500 000 hydrogeological map are shown in Figure 1.

To assist the consultants in their work, DWAF also commissioned an expert structural geologist from the University of Natal to produce a report on the structural geological conditions prevailing in the region and their likely effect on the groundwater regime. Hydrogeological maps and reports of the individual Mapping Units were reviewed by two external reviewers, Professor F.G. Bell and Mr J.R. Vegter, who reported on their adequacy to DWAF. The project was directed by Dr R.R. Maud acting as Project Co-ordinator because of his extensive local geological knowledge, and it was managed by two Project Managers from the Directorate: Geohydrology, Mr Z.M. Dziembowski and Mr W.R.G. Orpen.

It must be emphasised that the purpose of the project was not to conduct a full hydrocensus of every borehole in the area, but rather to obtain information regarding a sufficient number of boreholes so that statistically reliable characterisation could be made of the groundwater conditions prevailing in the project area. The project resulted in an increase in the number of borehole records on the NGDB, covered by the Vryheid 1:500 000 map sheet from 7 320 to 11 526.

1.2.2 The 1995–96 Crisis Intervention Programme

The most recent drought in 1995–96 expedited the drilling of 993 boreholes in rural areas of KwaZulu-Natal which were deemed to be in a critical water supply situation. The purpose of the programme was to drill and equip boreholes with hand-

pumps for the immediate relief of the suffering communities. Private consultants were employed to carry out borehole siting, drilling supervision, pumping tests, groundwater sampling and finally to give recommendations as to the use of each borehole.

The data generated during the programme were of high quality and were further used by King (1997) in her M.Sc. thesis entitled "The Development Potential of KwaZulu-Natal

Aquifers for Rural Water Supply". This thesis examined the potential yield and groundwater quality of individual aquifers in rural areas of KwaZulu-Natal.

1.2.3 Others

The KwaZulu-Natal Hydrogeological Characterisation and Mapping Project has been the only formal large-scale hydrogeological investigation carried out in KwaZulu-Natal. Umgeni Water has recently taken its own initiative to improve on local groundwater characterisation in its area of interest but as yet results have not been finalised (pers. comm. Umgeni Water, 1997).

A more in-depth study of aspects of groundwater occurrence, aquifer characteristics, recharge and optimal borehole siting were carried out in the late 1950's by W.L. van Wyk (1963) of the Geological Survey. His studies were confined to the central part of the Vryheid map.

Studies of groundwater occurrence around Richards Bay with extensive use of the electric resistivity method for aquifer exploration, drilling of boreholes and aquifer testing were performed during 1976-77 by P.F. Worthington of the CSIR (1978).

At the beginning of the 1990's, a comprehensive study of the Zululand coastal aquifer between Mtuzini and the Mozambique border was entrusted by the Water Research Commis-

sion (WRC) jointly to Environmentek, CSIR and the University of the Free State (Meyer, *et al.*, 2001). Following the evaluation of previous geohydrological investigations, an extensive, multi-technique, geophysical survey of the coastal intergranular aquifer was carried out, supported by only limited exploratory drillings. Hydrochemical survey and environmental isotope analyses elucidated the interdependence between lakes in the area and regional groundwater. The rainfall recharge study using chloride method provided a quantitative recharge rate determination. A preliminary application of the finite element aquifer modelling yielded more qualitative understanding of groundwater use by forest plantations. Upgrading of the model is strongly recommended.

Towards the end of the 1990's another geohydrological study of the unconsolidated coastal aquifer in Zululand was undertaken for the WRC by the University of Zululand (Kelbe, *et al.*, 2001). Aspects of interdependence of lakes and groundwater, regional groundwater dynamics, utilisation and pollution threats were studied in detail using numerical modelling techniques and model simulations.

1.3 Data collection

The borehole data used in the production of this hydrogeological map were primarily collected by consultants contracted during the KwaZulu-Natal Hydrogeological Characterisation and Mapping Project. Existing data on the NGDB were first verified because it was recognised that the quality of the data on the database suffered from poor co-ordinate accuracies and other deficiencies. Other records from the Department of Agriculture, the KwaZulu Department of Agriculture and

KwaZulu Department of Works were captured from hardcopy drillers' completion forms. Other data were collected from academic and industrial organisations in digital format.

Recent data extracted from consultants' reports from the Crisis Intervention Programme were entered into a local database for analysis but added to the NGDB for the purposes of the hydrogeological map.

1.4 Data limitations

The data collected and used in the compilation of this map were limited by a number of factors. The primary problem is the poor quality of the data available. Typical examples of these types of problems are very poor coordinate accuracy's, many in excess of 1 000 m; lack of basic hydrogeological data such as yield, strike depths and static water levels. The method of borehole siting of those boreholes, for which there are data, is often questionable. It is estimated that approximately 40% of the boreholes were sited non-scientifically. This means that the boreholes have not always been sited in the most appropriate hydrogeological location. Compounding this problem is the fact that many boreholes have also been sited in particular

places because it is close to the demand, again not in the most favourable hydrogeological location. Difficulties in obtaining access to the most favourable sites, due to dense vegetation and difficult terrain also means the boreholes are not sited in their optimum locations.

The hydrogeological map produced is only as good as the data that it is generated from. It is acknowledged that there are some flaws in the data, but only by ensuring that new borehole data are included in the NGDB can we be confident that the information portrayed on the hydrogeological map, and any future maps, is as true a reflection of the hydrogeology as possible.

1.5 Mapping methodology

1.5.1 Lithology

The basis of the hydrogeological map is the underlying lithology, as it is primarily the nature of the rocks that dictates the occurrence of groundwater. Therefore rocks with similar lithological characteristics have been grouped together. For example, there are numerous different types of argillaceous rocks within the Beaufort Group and these have been grouped into one lithological unit called P-Trb. The various groupings of Formations are discussed further in chapter 3.

The lithological boundaries on the hydrogeological map were obtained by digitising the geology from the Council for Geoscience 1:250 000 geological maps. Thereafter the Forma-

tions of similar lithology were grouped together. Sometimes it was necessary to smooth out intricate lithological boundaries to make the map more readable at a 1:500 000 scale. In cases where there were small "islands" of lithology, these were also excluded for the sake of readability. These changes mean that some lithological boundaries on the hydrogeological map will not correspond exactly to the 1:250 000 geological maps. Geological faults were also digitised from the same 1:250 000 geological maps. Some faults have also been removed in order to increase readability of the map.

1.5.2 Borehole yield

The lithology map was further subdivided or grouped into areas, which were delineated on the basis of geological structure, recharge and topography. These are important aspects that are considered to have an effect on the yield of boreholes. The resultant areas, therefore, represent areas of different hydrogeological characteristics.

A database of all borehole records with yield data was created. Dry boreholes or those with no data were excluded from analysis because it was impossible to distinguish on the NGDB which were dry or which had no data. This fact is unfortunate, as information regarding dry boreholes can be beneficial in determining the potential yield of an area. Use of only successful boreholes means that the map therefore portrays the likely yield of successful boreholes only. Yield data when it was available was usually the blow yield of the borehole. It is estimated that less than 10% of the borehole yield data were obtained by

controlled pumping tests.

Using a geographic information system (GIS), the borehole records were intersected with each hydrogeological area and statistics returned on the number of boreholes, standard yield deviation, median yield, maximum and minimum yield for each area. The results of this analysis were compared to the 1:250 000 hydrogeological maps produced by consultants during the KwaZulu-Natal Hydrogeological Characterisation and Mapping Project. Further refinements were made by checking each area for clusters of abnormally high or low yielding boreholes.

The borehole yield boundaries on the map generally follow the lithology boundaries. There are some cases where the borehole yield boundary does cut across the lithology, thereby reflecting distinct areas of higher or lower yield compared to the rest of the lithology.

1.5.3 Aquifer type

For the purposes of the 1:500 000 map series aquifers are divided into four types:

- intergranular
- fractured
- karstic
- intergranular and fractured

Intergranular Aquifer: a water saturated unconsolidated sediment such as sand and gravel, where water is stored in the intergranular pores and can be transmitted to boreholes and springs.

Fractured Aquifer: associated with hard rocks, where water occurs in fractures, faults, joints or fissures.

Karstic Aquifer: associated with carbonate rocks such as limestone and dolomite. Groundwater is stored and transmitted through fractures, solution cavities and channels.

Intergranular and Fractured Aquifer: water occurs in both the upper decomposed rock zone and the fractured but fresh rock formation below. These zones are in hydraulic contact. Weathering of crystalline rock can lead to the formation of this aquifer type.

Aquifers of the karstic type do not occur within the Vryheid map area.

Aquifer types and yield classes as they occur on the Vryheid map are indicated as "Principal groundwater occurrence," in a table on the right side of the main map. These aquifer types classify the voids in the rock through which water is transmitted.

The aquifer mapped was not necessarily the shallowest, but the principal aquifer. In other words, the principal aquifer is the shallowest aquifer with the highest yield and the best quality water. Thus a surface layer of sand with an insignificant groundwater yield would not be mapped as the aquifer if the deeper bedrock provides higher yields.

Intergranular aquifers are those which transmit ground-

water in the voids between individual grains. The formation of these voids may either be a result of primary sedimentation, e.g. unconsolidated coastal sands, or secondary process such as weathering of crystalline or sedimentary rocks.

Those rocks in which groundwater flow is mainly within fractures are classified simply as fractured aquifers. It is generally aquifers in competent rocks that fall into this category. However, many competent rocks also exhibit some weathering that may confuse one into believing that the aquifer should be classed as intergranular and fractured. The weathered or intergranular zones may store important quantities of groundwater in their voids, but the water can only be economically abstracted from fractures in the underlying bedrock.

Thus it is mainly from the fractured hard rock that groundwater is obtained.

Where a rock's intergranular zone does contribute significantly to the transmission of groundwater in conjunction with fractures, the aquifer is classed as intergranular and fractured. This is often the case in crystalline rocks, which tend to be susceptible to weathering in hot humid climates. It is both within the intergranular weathered zone and fractures that groundwater can be obtained, with the intergranular zone also acting as a storage zone for downward percolating groundwater.

The distribution of the three different aquifer types found on the hydrogeological map is shown in Figure 2.

1.5.4 Groundwater quality and hydrochemistry

Data points containing electrical conductivity (EC) readings were contoured, using inverse distance weighting, to distinguish regional-scale trends. The quality parameter of EC was chosen because it is the most commonly measured water

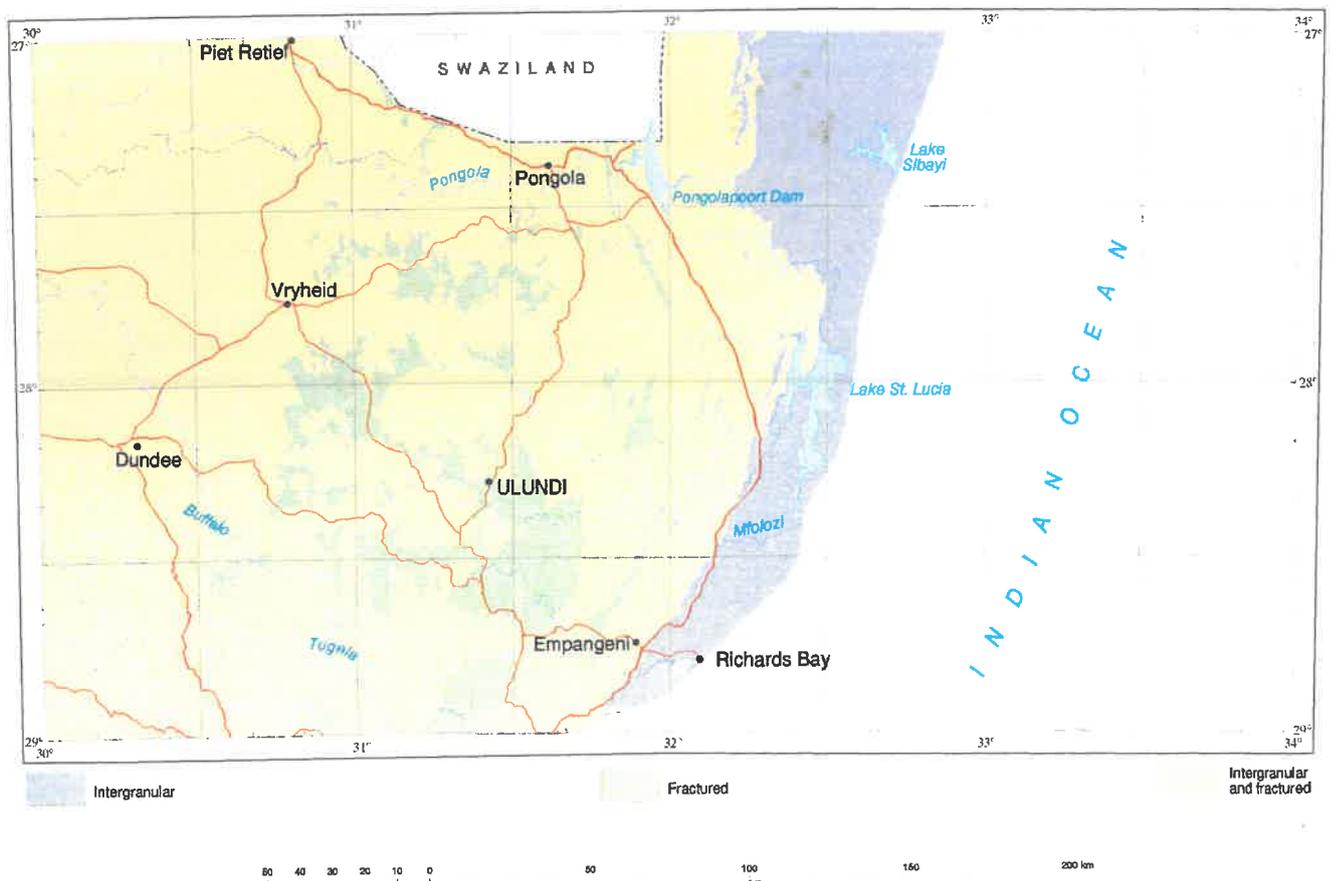
quality variable, it reflects high salinity and/or is a good indicator of pollution. Lithologies exhibiting known influences on EC were used as boundaries and contoured separately.

1.5.5 Major groundwater use

The location of large-scale groundwater abstraction points were obtained through the experience of both the map author, KwaZulu-Natal Hydrogeological Mapping project consultants

and Dr R.R. Maud. An estimate of the abstraction rate was determined from abstraction reports or from the owners of the schemes.

Figure 2. Distribution of aquifer types



2 Physical environment

2.1 Physiography

The most noticeable feature on the map sheet is the Maputaland Coastal Plain, which is found along the northeastern seaboard. This low level feature lies below an elevation of 100 m and commences just north of Mtunzini, becoming progressively wider northwards, where it reaches 75 km in width at the Mozambique border. In the north, this plain is bounded on the west by the narrow north-south trending linear upland feature of the Lebombo range (Ubombo) that rises to an elevation of some 700 m in the north, its crest declining in a southerly direction. This range is paralleled on its western side

by the 'Lowveld' over which elevation is again only 250 m on average. West of the 'Lowveld' and over the rest of the region to the south, elevations increase fairly steeply in an inland direction before flattening out or declining about 100 km from the coast in the broad interior basins of the major rivers. The coastal hinterland is deeply dissected by the major rivers with relief approaching 1 000 m between the Kranskop plateau and the Tugela River valley below it in the central south. The topographic conditions prevailing in the area are illustrated as an inset map on the Hydrogeological Map.

2.2 Climate

2.2.1 Precipitation

Rainfall is strongly orographically related, with the elevated portions of the area experiencing greater rainfall than the more low-lying areas, except along the coast. Over the northern parts of the Maputaland Coastal Plain, rainfall declines progressively with increasing distance from the coastline. Most rainfall occurs in the summer months, usually as a result of seaward-moving convective thunderstorms. Other rainfall is frontal and associated with the passage of cold fronts from the southwest. Very occasionally the north east of the region may experience waning Indian Ocean cyclonic rainfall. The distri-

bution of rainfall is illustrated on the General Hydrogeological Map as an inset map. See also Table 1 for average rainfall of selected stations.

Table 1. Representative average rainfalls

CITY/TOWN	AVERAGE ANNUAL RAINFALL (mm)
St Lucia	1291
Richards Bay	1102
Piet Retief	897
Vryheid	863
Dundee	837
Melmoth	804
Wakkerstroom	773
Pongola	638

2.2.2 Evaporation

Mean annual evaporation (Symons Pan) over the area varies from about 1 300 to about 1 800 mm. At Pongola and Dundee evaporation exceeds 1 500 mm/a and evaporation at Dundee amounts to 1 440 mm/a. (Figure 3)*.

2.3 Surface hydrology

The major river occurring on the map is the Tugela River, which passes through the southern part of the map area. This river, with its major tributaries, the Mooi and Bushmans Rivers, has its source in the Drakensberg escarpment beyond the western margin of the map. Farther north, the Sundays and the Buffalo Rivers, have their sources in the northward extension of the Drakensberg escarpment. In the north, the Pongolo River and its tributary, the Bivane, have their source on the same escarpment as does the Assegai River, which passes through the extreme north of the map area.

Other major rivers having their source on the high ground

in the west of the map area are the Mfolozi and the Mkuze Rivers. Significant rivers having their source in the coastal hinterland in the south are the Mlalazi, Mhlatuze and Hluhluwe Rivers.

The Maputaland Coastal Plain contains Lake Sibayi, which is the largest natural fresh water lake in the country. Other fresh water lakes (some too small to feature on the map) of significance on the Maputaland Coastal Plain are Lakes Cubhu, Mzingazi, Nhlabane and Bhangazi. The salinity of these lakes varies with distance from the sea and is also affected by seasonal inflow from rivers draining into them.

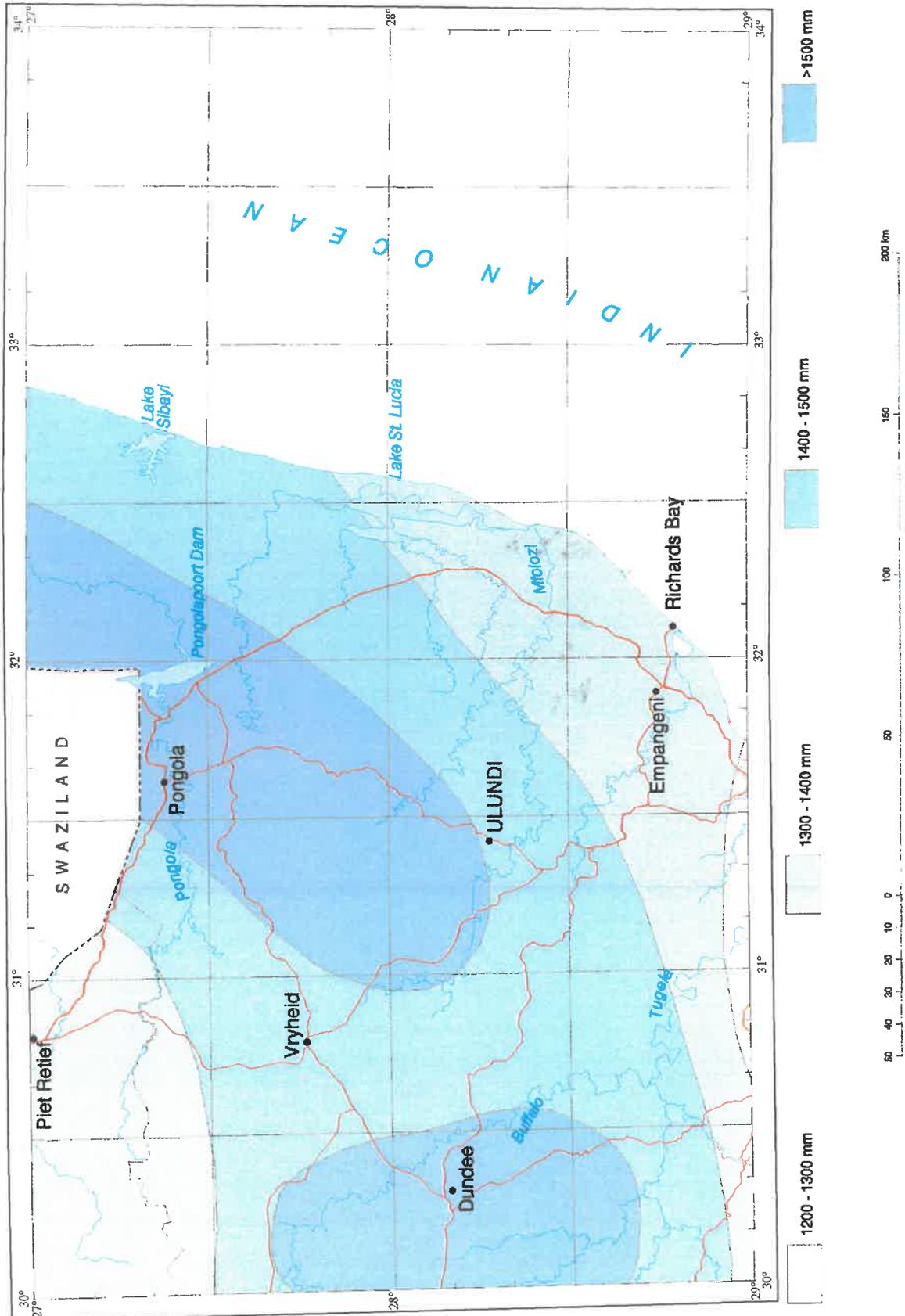
*Figure 3 is a much generalised map of evaporation in the map area. Some discrepancies between data on the map and individual stations may occur.

Lake St Lucia is a recently declared World Heritage Site. The lake or estuary is the largest natural surface water feature in South Africa covering an area of 38 000 ha. Even though the majority of inflow into the lake is from surface water, the system is maintained, especially during low flow periods by groundwater – either directly or indirectly by feeding the rivers

that discharge into the lake.

A number of large dams have been constructed within the mapped area. The Pongolapoort Dam is the largest and has a capacity of $2\,446 \times 10^6 \text{ m}^3$. Other dams include the Heyshope, Goedertrouw, Zaaihoek, Hluhluwe, Klipfontein and Paris Dams.

Figure 3. Mean annual pan evaporation



3 Geology

3.1 Introduction

The geology depicted on the hydrogeological map incorporates the most recent proposals and decisions by the S.A. Committee for Stratigraphy and will thus differ with older published geological literature and maps.

In many instances it has been possible in the lithological legend to combine a number of stratigraphic units at Formation level within the major stratigraphic units at Group or Supergroup level. This is possible, even for rocks and unconsolidated material of different geological ages because they may

have the same hydrogeological properties. Two examples of this are the argillaceous sedimentary rocks such as shales and mudstones of the various Formations of the Karoo Supergroup, and the unconsolidated coastal sediments. The generalised lithology legend shown on the map sheet is therefore a product of the grouping of similar lithologies and does not reflect the actual stratigraphy of the rock formations. A summary of the groupings is given in Table 2 and a simplified lithology map (Figure 4) shows the distribution.

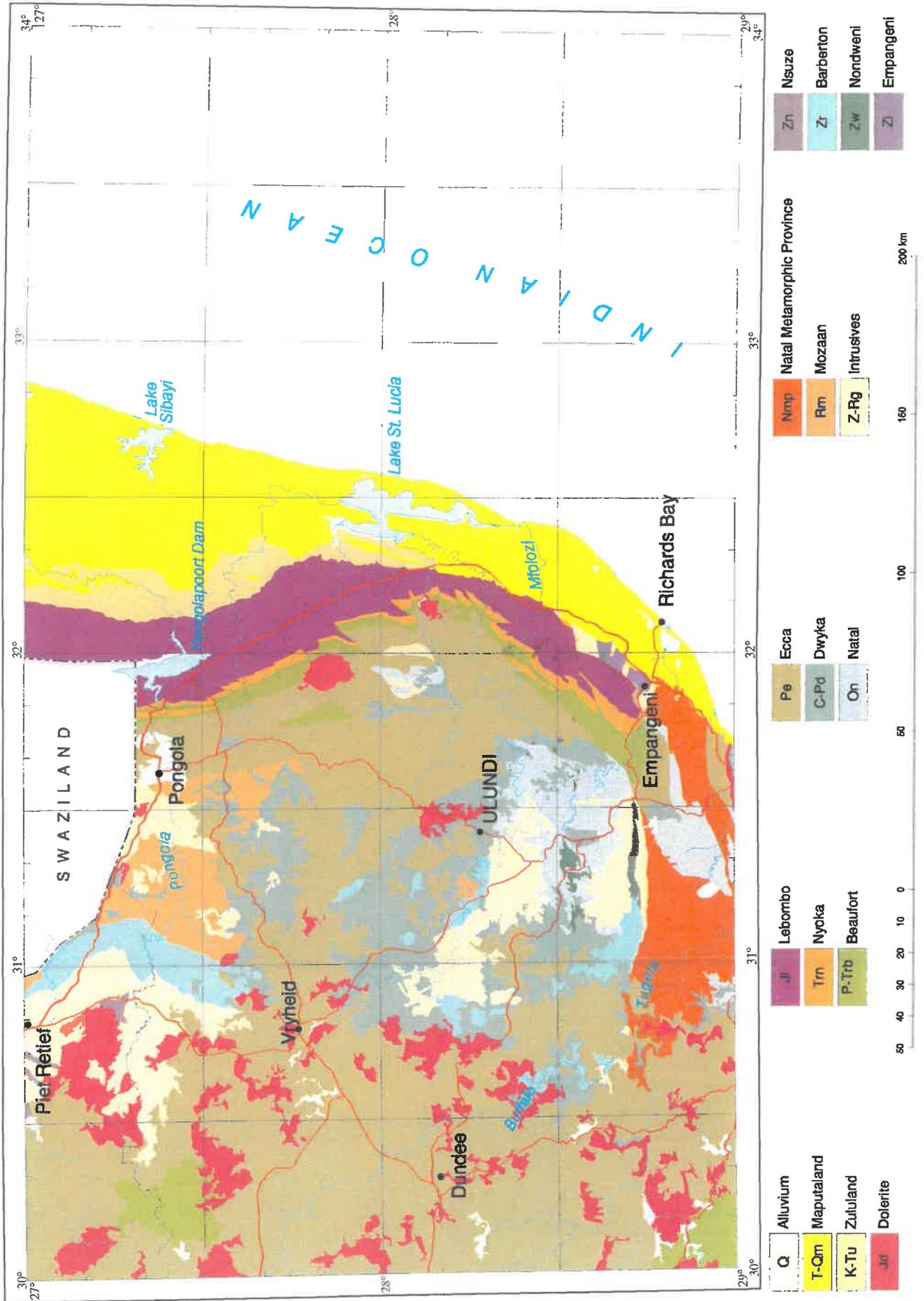
Table 2. Summary of lithological groupings and their symbols on the hydrogeological map

SYMBOL ON MAP	GENERALISED LITHOLOGY	HYDROGEOLOGICAL MAP GROUPING	MAJOR STRATIGRAPHIC UNIT
Q T-Qm	alluvium coastal sediments	Fluvial deposits Maputaland Group	Quarternary Tertiary-Quarternary
K-Tu	siltstone, sandstone, conglomerate	Zululand Group	Zululand Group
Jd	dolerite	Karoo Dolerite	Karoo Supergroup
Jl	basalt and rhyolite	Lebombo Group	
Trn	sandstone and mudstone	Nyoka Formation	
P-Trb	shale, siltstone, sandstone	Beaufort Group	
Pe	mostly shales, carbonaceous shales and mudstone with the exception of the Vryheid Formation sandstones	Ecca Group	
C-Pd	diamictite	Dwyka Group	
On	sandstone	Natal Group	Natal Group
Nmp*	granite, granitic gneiss, gneiss, calc-silicate rocks, granulite, charnockite, amphibolite and marble	Natal Metamorphic Province	Natal Metamorphic Province
Rm	shale, sandstone, quartzite, conglomerate, iron formation	Mozaan Group	Pongola Supergroup
Z-Rg	granites, granitic gneisses, ultramafic diabase and syenite	Intrusives	Pre- and Post-Pongola Supergroup
Zn	shale, quartzite, basaltic lava, dolomite, sandstone, mudstone, siltstone, iron formation, schist	Nsuze Group	Pongola Supergroup
Zr	amphibolite, schist, chert, iron formation	Barberton Supergroup	Barberton Supergroup
Zw	basic lava, chert, calc-silicate rocks, schist, quartzite, conglomerate, ironstone	Nondweni Group	Nondweni Group
Zi	amphibolite, pyroxenite, granulite, gneiss	Empangeni Metamorphic Suite**	Empangeni Metamorphic Suite

*Note: The geological symbol "Nmp" was adopted from the 1984 x 1:1 000 000 scale published geological map. This symbol might give the impression that most of the rock units of the Natal Metamorphic Province are of the Namibian erathem, while they are in fact of the Mokolian erathem.

**Note: On the map, indicated as Group.

Figure 4. Principal geological units



3.2 Nondweni Group (Zw)

These very ancient rocks comprising highly folded and jointed schistose lavas (greenstones), cherts, quartzites and banded ironstones occur to a limited extent (135 km²) northwest of Melmoth.

3.3 Empangeni Metamorphic Suite (Zi)

These rocks occur in the Empangeni area, covering a surface area of 78 km². The lithology of these rocks comprises amphibolitic rocks and pyroxene-rich granoblastites interbanded with gneisses and granulites. These rocks have been subjected to high-grade metamorphism.

3.4 Barberton Supergroup (Zr)

In the north, between Paulpietersburg and Piet Retief, a few occurrences of talc schists and amphibolites of the Barberton Supergroup are present in the general granite terrain. These rocks only cover 67 km² of the mapped area.

3.5 Pongola Supergroup

3.5.1 Nsuze (Zn) and Mozaan (Rm) Group

The rocks of the Pongola Supergroup are of limited occurrence in the map area, where they have been exposed by erosion removal of the overlying Karoo rocks. The Nsuze Group occurs to a limited extent in the north-central portion of the map area, mainly in the area between Ulundi-Nkandhla-Vryheid, while the Mozaan Group rocks occur more extensive-

ly in the north, east of Vryheid and Paulpietersburg. Both groups of rocks have undergone low-grade regional metamorphism and comprise mainly quartzites, andesitic lavas and shales. The rocks of both groups are characteristically highly folded and jointed, the dip in many places being near vertical.

3.6 Intrusives (Z-Rg)

For the purposes of this map, both pre- and post- Pongola intrusives have been grouped together and have the symbol Z-Rg. The pre-Pongola granitic basement rocks comprise granites and granitic gneisses, which occur fairly extensively in the area to the north of Paulpietersburg, in the central parts of the map area northeast of Babanango and south of Melmoth.

These rocks are intrusive into the Nondweni Group and Empangeni Metamorphic Suite.

Several episodes of intrusion after the formation of the Pongola Supergroup led to the occurrence of ultramafic dykes, the layered sheet of the Hlagothi Suite, diabase sills and dykes, porphyritic dykes and syenite.

3.7 Natal Metamorphic Province (Nmp)

The northern contact of the Natal Metamorphic Province with the older Kaapvaal Craton rocks coincides roughly with the west-east striking Tugela Fault west of Empangeni. The Ngoye gneiss occurs extensively south of Empangeni and exhibits some southwest-northeast foliation and well developed jointing.

Rocks of the Tugela, Mfongozi, Ntingwe and Mapumulo Groups comprise a varied assemblage of rock types that range

from gneisses, through schists, to metagabbros, amphibolites and pyroxenites. The Mfongozi Group contains dolomitic marbles. The rocks of the Mapumulo Group are generally less basic than those of the other groups. All the rocks of these groups are strongly and steeply foliated and jointed in the prevailing southwest-northeast to west-east major structural trend direction of the Natal Metamorphic Province.

3.8 Natal Group (On)

The rocks of this group comprise an upper Mariannahill Formation and a lower Durban Formation. They occur through the eastern portion of the map, thinning away completely to the north and west where the Dwyka Group rests directly on the Natal Metamorphic Province. The combined thickness of the two Formations in the Eshowe-Melmoth area is 300 to 400 m but elsewhere it is much less than this due to Dwyka glacial erosion. In the Ulundi-Nkandhla areas, the base of the succes-

sion is characterised by a lithified cobble and boulder conglomerate (the Ulundi member). This conglomerate is more than 100 m thick in the Nsuze River valley west of Melmoth, but is 10 to 20 m in thickness south of Ulundi. The Mariannahill Formation comprises almost entirely pinkish well-bedded arkosic sandstones. The Durban Formation comprises erosion-resistant pinkish well-bedded arkosic sandstone and quartzite with minor intercalated shale.

3.9 Karoo Supergroup

3.9.1 Dwyka Group (C-Pd)

This glacially derived basal unit of the Karoo Supergroup rests unconformably on the uneven surface of a variety of underlying geological formations. The rounded hill and valley topography, sculpted by the continental ice-sheet on the underlying erosion-resistant rocks, can be one of considerable relief in places. The Dwyka Group comprises mainly massive, unbedded but jointed diamictite with subordinate fine sandstone and shale intercalated horizons in places. The diamictite comprises

a dark-coloured, fine, muddy matrix in which erratic clasts of various older resistant rock-types, such as granite-gneiss, quartzite and chert that vary in size from pebbles up to large boulders occur. The formation outcrops as a discontinuous broad band through the central and in some places in the faulted eastern portion of the map. The thickness of the diamictite is usually less than 100 m.

3.9.2 Ecca Group (Pe)

The lowermost Formation of the Ecca Group is the Pietermaritzburg Formation, which comprises a succession of dark-coloured shales. It occurs as a scattered, broad, north-south band through the west central portion of map area, as well as in places in its faulted eastern portion. The formation thickens from less than 100 m in the north to about 250 m in the south.

Overlying the Pietermaritzburg Formation is the Vryheid Formation, which is the most extensive of all the geological formations occurring in the map area. The formation occurs extensively in the west and northwest as well as in the central northeast and in the faulted coastal southeastern parts. The thickness of the Formation varies from approximately 300 to

500 m in the interior and north, but less in the southeast. It comprises an alternating succession of micaceous shales and medium - to coarse-grained arkosic sandstones, the shales frequently being carbonaceous. This Formation contains the major KwaZulu-Natal coalfields of Klip River-Dundee and Newcastle-Utrecht and Vryheid-Paulpietersburg.

The Normandien (Estcourt) and Volksrust Formations are the youngest of the rocks of the Ecca Group and comprise mainly shales and mudstones. Thin occurrences of the Volksrust Formation crop out from beneath the Emakwezini Formation in the northeast. The combined thickness of the two Formations is about 500 m.

3.9.3 Beaufort Group (P-Trb)

The Emakwezini Formation represents the Beaufort Group in the northeast. It comprises about 500 m of shales and fine-grained sandstones with some siltstones. It partly correlates

with the Normandien (Estcourt) Formation in the west of the map area. Eleven low-grade coal seams occur mainly towards the middle of the Formation.

3.9.4 Nyoka Formation (Trn)

This Formation comprises fine-grained sandstones and mudstones. The approximate thickness is 285 m. The distribution of the Nyoka Formation, together with the minor Clarens and Ntabene Formations is restricted to a narrow easterly-dipping band immediately west of the Letaba Formation (Lebombo Group) basalts.

The Clarens and Ntabene Formations have not been included on the map due to their narrow extent, which at a 1:500 000 scale is impossible to represent. For description purposes, the Clarens Formation comprises massive, fine-grained sandstone and the Ntabene Formations comprises sandstones with some interbedded shales.

3.9.5 Karoo Dolerite (Jd)

Intrusive into all older hard rock units are dykes and sills of Karoo dolerite. Dykes varying in width from 1 to 8 m are common in the Karoo Supergroup sedimentary rocks in the interior, but are much less common in the older rocks nearer the coast (Figure 5). A major north-south aligned dyke swarm characterises the upper-most sedimentary rocks of the Karoo Supergroup as the Rooirand, on either side of the Pongolo River, northwest of Mkuze village. Most dolerite dykes have a vertical or near-vertical dip except in the east where they have a westward dip (due to the regional structure).

Intrusive dolerite sills vary in thickness from about 1 m to 50 m or more. They become more frequent and thicker in the subhorizontal upper portions of the overall stratigraphic succession in the interior, particularly in the sediments of the Ecca and Beaufort Groups. A major subhorizontal dolerite sill, that is over 100 m in thickness, caps the prominent Mynathi, Mashongololo, Hlobane and Zungwini mesa features around Vryheid. The increase in number and thickness of dolerite sills with increasing height in the stratigraphic succession is

probably due to both relative ease of injection into the well-bedded sedimentary rocks of the upper portion of the succession, and the lower rock loading that prevailed, which permitted the easier injection of the molten dolerite rock with increasing elevation in the succession. Many of the thicker dolerite sills show evidence of multiple phases of injection. A major dolerite-related differentiated intrusion comprising gabbros, norites and anorthosites is present in the faulted and tilted upper Karoo sedimentary rocks northwest of Hluhluwe village. The dolerite sills vary in attitude from horizontal to inclined, but most are sub-concordant with the bedding of the host sediments. In the southern coastal zone a more siliceous, somewhat younger, form of dolerite termed 'Effingham-type' also occurs as sill intrusions in the fault-tilted Karoo sediments. The rocks immediately adjoining dolerite intrusions, of both dyke and sill form, are frequently disturbed and fractured, and thermally metamorphosed, as a result of the injection of the dolerite.

3.9.6 Lebombo Group (Jl)

The extrusive igneous rocks of this Group comprise rhyolite and basalt. Layered rhyolites and dacites of the Jozini Formation form the prominent, relatively narrow, north-south trending, easterly dipping feature of the Lebombo mountain range in the northeast of the map area, on account of their relative resistance to erosion. They are frequently intruded by north-south striking Karoo dolerite dykes. The thickness of this unit in the north is > 8000 m. Northwest of Hluhluwe, a number of prominent major and minor dykes of rhyolitic

breccia in the Karoo sediments are also associated with this Formation.

Beneath the rhyolite are found the basalts of the Letaba Formation. This easterly dipping formation is the local equivalent of the Drakensberg Group basalt occurring in the southwest of the KwaZulu-Natal province. The rocks of the Letaba formation comprise a thick succession of > 2000 m of layered tholeiitic basalts. In the north of its area of occurrence it also contains numerous north-south striking dolerite dykes.

3.9.7 Bumbeni Complex

The occurrence of this mainly volcanic complex is limited to a relatively small area at the southern end of the Lebombo range, north of Hluhluwe (not indicated separately on the main map). The rocks of the Complex, which unconformably

overlie the rhyolite-dacites of the Jozini Formation, comprise basalts and pyroclastic welded tuffs, along with some plug intrusions of syenite.

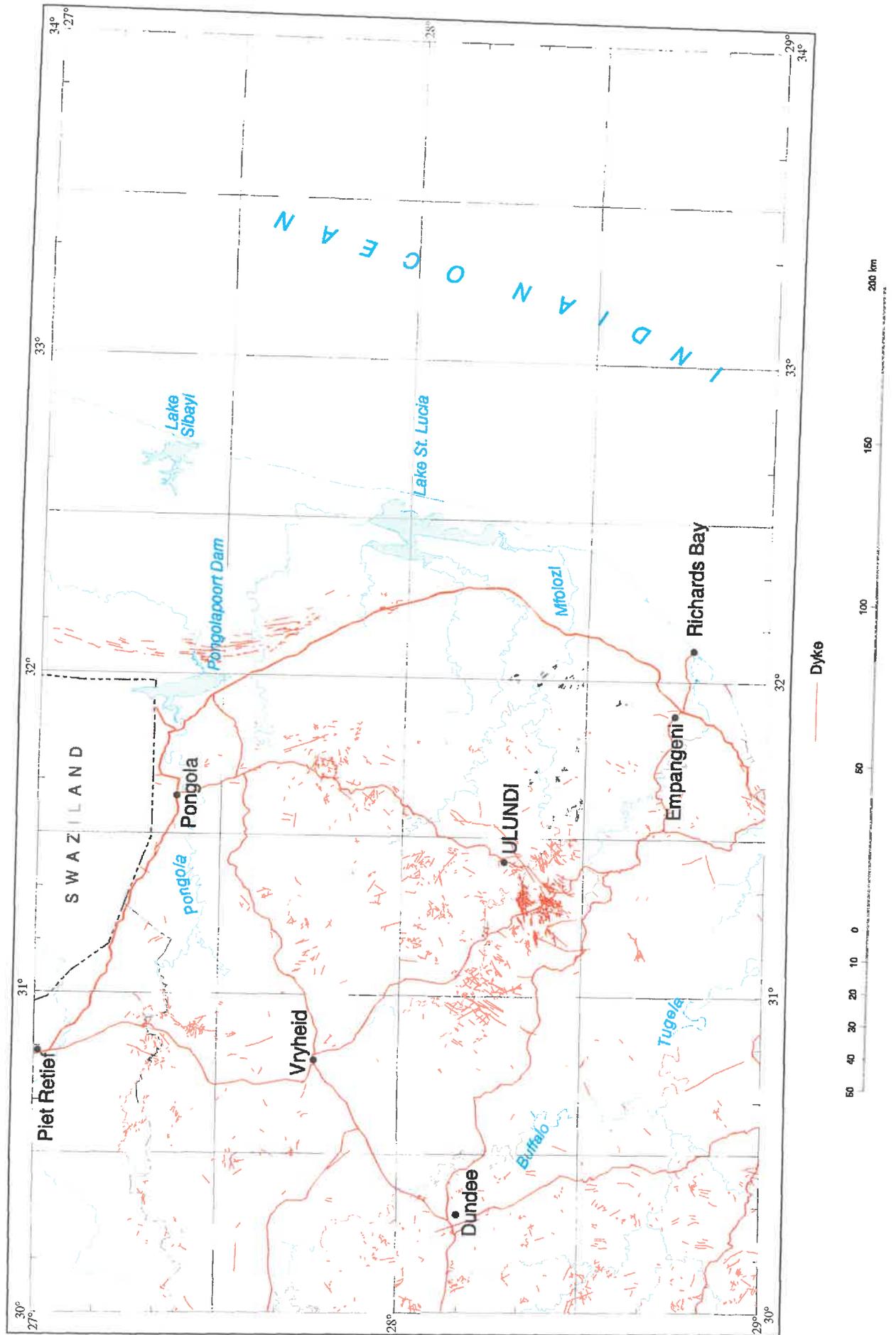
3.10 Zululand Group (K-Tu)

3.10.1 Makatini, Mzinene and St Lucia Formations

The three Formations of the Zululand Group underlie the entire Maputaland Coastal Plain. They are of marine origin and span the whole geological period of the Cretaceous age. The St Lucia Formation transgresses the Cretaceous-Tertiary boundary in time into the Palaeocene. The Formations occur successively in an eastwards direction, they also becoming younger in this direction. The oldest is the Makatini Formation, which outcrops along the foot of the Lebombo range in the west. The succession thickens as a wedge from west to east, from zero at the foot of the Lebombo range to some 1 800 m at

the coast near Sodwana Bay. The Formations are covered by younger sediments of Tertiary and Quaternary age. Exposures are found in the west as a result of erosion in riverbanks, and around False Bay where high cliffs of 20 m occur. The Makatini Formation comprises a thick basal conglomerate (about 150 m thick), which is overlain by siltstones, fine-grained sandstones, mudstones and intercalated thin concretionary limestone horizons of the succeeding two formations. All the formations are highly fossiliferous, except possibly in the case of the conglomerates of the Makatini Formation.

Figure 5. Dolerite dyke distribution



3.11 Quaternary and Tertiary sediments

3.11.1 Maputaland Group (T-Qm)

Each individual Formation of the Maputaland Group has not been represented on the hydrogeological map as the Council for Geoscience is still in the process of mapping out the new stratigraphy. All the Maputaland Group sediments have been

grouped as one unit, but distinct lithologies are depicted separately on the map with different hatching. A description of all the proposed Formations is, however, given to enable one to distinguish one from another in the field.

3.11.1.1 Uloa and Umkwelane Formations

These two Formations are of Late Miocene and Earliest Pliocene age and rest unconformably on the underlying Cretaceous rocks. The older Uloa Formation underlies the central portion of the Maputaland Coastal Plain around Richards Bay, at Uloa east of Mtubatuba and on the peninsulas separating False Bay from the main St. Lucia lake farther north. Its thickness is about 10 m and comprises mainly marine shelly coquina. It is overlain by marine and aeolian (lower and

upper) calcarenites of the Umkwelane Formation, the surface of which is extensively karstified with a thick overlying mantle of weathering-derived Berea-type red sand which may be up to about 50 m in thickness. The remaining unweathered formation may be up to about 20 m in thickness and occurs mainly intermittently along the western margin of the Maputaland Coastal Plain.

3.11.1.2 Port Durnford Formation

The Port Durnford Formation is of Middle to Late Pleistocene age. The Formation has an approximate thickness of 20 m and comprises flat lying but locally slumped mudrock, calcarenite and sandstone with a discontinuous lignite horizon. It occurs mainly beneath the southern portion of the Maputaland

Coastal Plain within a distance of about 5 km of the coastline where it is exposed on prominent sea cliffs, north and south of Richards Bay. Inland, it is covered by the Kosi Bay and Kwambonambi Formations. A perched water table is frequently associated with exposures of this formation.

3.11.1.3 Kosi Bay Formation

This unconsolidated Formation of aeolian sands, with localised calcarenites, of Late Pleistocene age underlies the majority of the northern Maputaland Coastal Plain. Its surface, however, has been mostly reworked into the Kwambonambi Formation. It has a thickness of up to 100 m in

places. A perched water table is frequently associated with the more clayey weathered section. In some localities, weathering of the formation has progressed sufficiently to form Berea-type red sand.

3.11.1.4 Berea-type red sand

This material is a regolith of variable depth of up to about 50 m that has developed by weathering of the underlying calcareous and non-calcareous dune sands of the Kosi Bay and Port Durnford Formations. It forms a number of dune-type 'cordons' on the Maputaland Coastal Plain that are more or less parallel to the coastline. It also occurs along the coastline itself south of Mtunzini, which is the southern limit of the coastal plain. North of Mtunzini it has developed on calcarenites of the Umkwelane Formation along the inland margin of the coastal plain where these rocks crop out intermittently. As the Berea-type red sand is an in-situ weathering product, it cannot be classified as a true geological formation. Depending

upon the age of the material on which it is developed and thus the time that has been available for the weathering that has produced it, the material can vary in texture from sands to sandy clays and in colour from light reddish brown to red in colour. In general, it gets sandier and less weathered and lighter in colour with increasing depth. South of Mtunzini, and along the inner margin of the Maputaland Coastal Plain, a basal boulder bed, approximately a metre in thickness, of waterworn erosion-resistant cobbles and boulders of sandstone, may – in places – overly older marine-cut terraces in the underlying bedrock.

3.11.1.5 Kwambonambi Formation

This superficial Formation of mainly Holocene age comprises redistributed grey sands and stabilised dunes. It has extensive occurrence over most of the inland portions of the Maputaland Coastal Plain and is up to 10 m thick.

3.11.1.6 Sibayi Formation

This Formation is also of Holocene and Late Pleistocene age. It comprises up to 130 m of calcareous and siliceous coastal dune sand. In the Sokhulu dunes near Cape St. Lucia, the

Formation attains a maximum height of 182 m. It occurs immediately inland of the coastline more or less continuously along its entire length within the map area.

3.11.2 Alluvium (Q)

Alluvium of Holocene and Late Pleistocene (Quaternary) age occurs along the courses of the rivers and streams of the map area. It is unconsolidated and varies vertically in texture from sands to clays. Sands invariably occur in the bed of the existing river or stream channel, with the more clayey sediments generally underlying the adjoining flood plain and higher-standing river terraces. Clayey and silty sediments are of general occurrence in the estuarine or lower lagoon portions of lowermost courses of the rivers, particularly in the case of the major rivers. Thickness of alluvium varies from a metre or less, to as much as 60 m at the mouths of the major rivers. A

characteristic of the major rivers of the region, is the occurrence of marginal lakes in tributary valleys adjoining their lowermost courses, which comprise partially alluvium-infilled former valleys. These lakes and former lakes are underlain by very soft organic clays known locally as 'Hippo Mud'. Examples of such marginal lakes are the Mzingazi and Qupu lakes on the Mhlatuze River system at Richards Bay, the Teza lake and others on the Mfolozi River near Mtubatuba, and the various 'pans' that characterise the course of the Pongolo River east of the Lebombo range in the extreme northeast of the area.

3.12 Structural geology and tectonics

Two major structural and tectonic events have affected the area covered by the Vryheid map sheet. The first and earlier of these was the Kibaran orogeny some 1 000 million years ago during which the Natal Metamorphic Province was formed, and the second some 160 million years ago when the disruption of Gondwana gave rise to the present eastern side of the African continent.

The effects of Kibaran orogeny (Thomas *et al*, 1994) are seen in the types of rocks, structures and metamorphic effects that have occurred in the younger Basement rocks of the area, south of the much older and stable Kaapvaal Craton. The Kaapvaal Craton's southern boundary occurs just to the north of the southern boundary of the map area. The Kibaran orogeny gave rise to sheet thrusting from south to north. The contact of this thrusting of the Natal Metamorphic Province rocks against the Kaapvaal Craton is expressed as the Tugela Fault. This process induced the southwest-northeast and west-east major foliation strike direction and jointing structural features that characterise these rocks today.

The coastal and coastal hinterland portions of KwaZulu-Natal are part of the rifted eastern margin of the subcontinent that was formed at the time of the breakup of Gondwana. These areas therefore are intensely faulted. The main geological structure are tilted fault blocks and some associated horst and graben structures. The most notable of which are the Ngoye horst and the Nkwalini graben which are situated in the

southeast of the map area and the Hlabisa horst located farther to the north. Most of the blocks, as in the intensely strike-faulted area north of Empangeni, are tilted in a seaward direction at angles of between about 5 and 15 degrees. The down faulted major block on the coast between the Tugela and Mlalazi Rivers, in the southeast, dips inland towards the Ngoye horst.

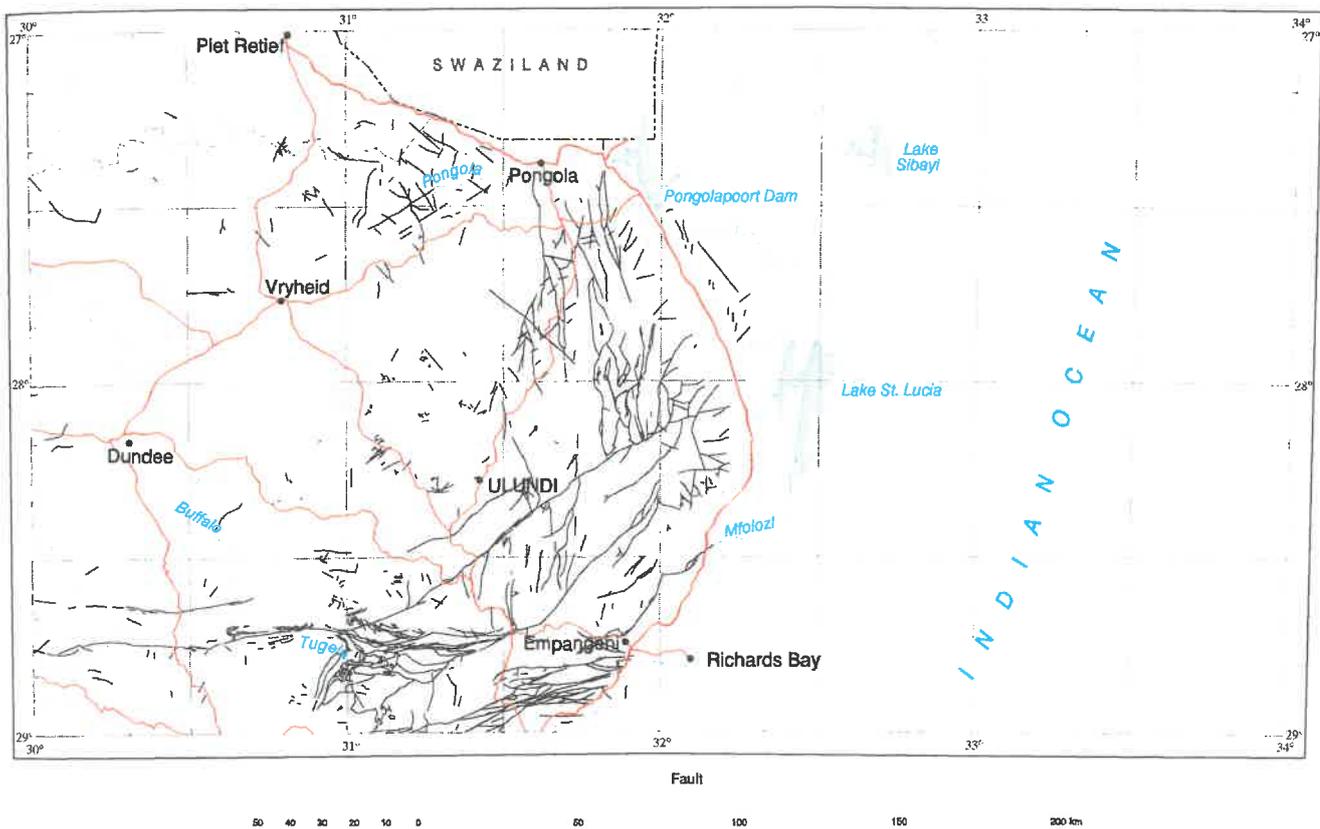
The faults of the coast and coastal hinterland over the southern half of the map area, south of Hluhluwe village, form part of a conjugate shear fracture pattern whose two main directional elements are south-north and southwest-northeast (Maud, 1961, von Veh and Andersen, 1990). North of Hluhluwe, the south-north linear tensionally faulted 'monoclinial' structure of the Lebombo becomes predominant. The southwest-northeast fault strike direction of the south being replaced entirely by the south-north fault strike direction only. On the eastern side of the Lebombo, the inclination of the easterly dipping lava flows increases to 20 degrees and more. The structure and volcanic stratigraphy of the Lebombo have most recently been reviewed by Bristow (1983) and Bristow and Cleverly (1983). In the interior of the region, the general bedding dip of the Karoo sediments is usually to the west at about 2 to 3 degrees, although locally it can have been disturbed by Karoo dolerite intrusions.

All the Gondwana-breakup (end of Jurassic) faulting in the coastal portion of the map area is of the tensional or normal

type. Vertical displacement on faults can be over 1 000 m. This is the case of the Eteza Fault, north of Empangeni, where the Letaba Formation basalt has been dropped against cratonic 'Basement' rocks. Bisecting the southernmost portion of the map area is the major west-east striking Tugela Fault. This fault, and its northeastwards extension to the east, is over 200 km in combined length. Downthrow on the fault is to the south, displacement on it varying from 300 m in the west to about 800 m in the east. In the west it is paralleled by another smaller fault on its northern side. As mentioned previously, the Tugela Fault also approximates the contact of the younger Natal Metamorphic Province on the south with the Kaapvaal Craton on the north. Some minor seismic activity continues in the region today in the zone trending northward from Empangeni, west of the Lebombo and into Swaziland. This activity

also extends offshore. In 1932, the epicentre of a major earthquake of approximately 6.5 on the Richter scale was located about 40 km offshore of Cape St Lucia (Fernandez and Guzman, 1979). There is no evidence, however, of significant movement on faults in the region since the major rift-faulting episode at the end of the Jurassic. However, there is some evidence for neotectonic fault movement in the Quaternary rocks in the area where the Mkuze River emerges from the Lebombo on to the Maputaland Coastal Plain to the east. This evidence is based on the fact that the Umkwelane Formation of late Miocene to Pliocene age has been downfaulted some 30 m or more to the north on what is apparently a west-east striking fault. Figure 6 illustrates the main fault features within the map area.

Figure 6. Geological fault distribution



4 Hydrogeology

4.1 Introduction

Groundwater occurrence is represented on the Hydrogeological Map by the various colours overlaying the lithological hatching. These colours represent both the nature of the aquifer and the expected yield ranges of successful boreholes. The nature of the different aquifers is mostly a result of their

lithology, structural history and climatic location. The lithological groupings have been grouped into intergranular, fractured or intergranular and fractured aquifer types according to their hydrogeological nature (Table 3).

Table 3. Summary of aquifer types for the Vryheid hydrogeological map

INTERGRANULAR	FRACTURED	INTERGRANULAR & FRACTURED
Maputaland Group	Dwyka Group	Empangeni Metamorphic Suite
alluvium	Natal Group	Barberton Supergroup
	Nyoka Formation	Mozaan and Nsuzze Group
		Intrusive rocks
		Natal Metamorphic Province
		Karoo Supergroup sedimentary rocks
		Lebombo Group
		Karoo dolerite
		Zululand Group

Each aquifer type and its groundwater occurrence is briefly discussed in the following sections. The yield histograms presented were constructed using only records with yield values. Due to it being impossible to distinguish between dry boreholes or boreholes with no data on the database, these have not been included. The exclusion of these boreholes does affect the overall appearance of the graphs, often giving the impression that a particular aquifer does not have low yields, when in fact, it

may have a greater number of dry boreholes than any other yield category. In order to present a more realistic figure, the approximate success rate is also given. Success, for this purpose, is defined as a borehole that is not dry.

A trilinear Piper diagram for each aquifer type is presented to show the average chemical composition of the groundwater. Appendix A presents a table listing the acceptable ranges of chemical constituents for domestic use of water.

4.2 Intergranular aquifers

4.2.1 Maputaland Group (T-Qm)

The rocks of the Port Durnford Formation and the unconsolidated sands of the Kosi Bay, Kwabonambi and Sibayi Formations mostly comprise fine- to medium-grained material with localised coarser-grained layers. It is these coarser-grained layers which can produce significant amounts of groundwater. Groundwater is also found in the finer sand, although its lower transmissivity reduces its potential. Most aquifers in the Maputaland Group are unconfined or semi-confined. Groundwater levels are generally shallow (< 10 m) in low lying areas, and 50% of all boreholes have groundwater levels less than 15 m below ground level (Figure 7). The likelihood of drilling a successful borehole in these aquifers is very good, usually greater than 95%.

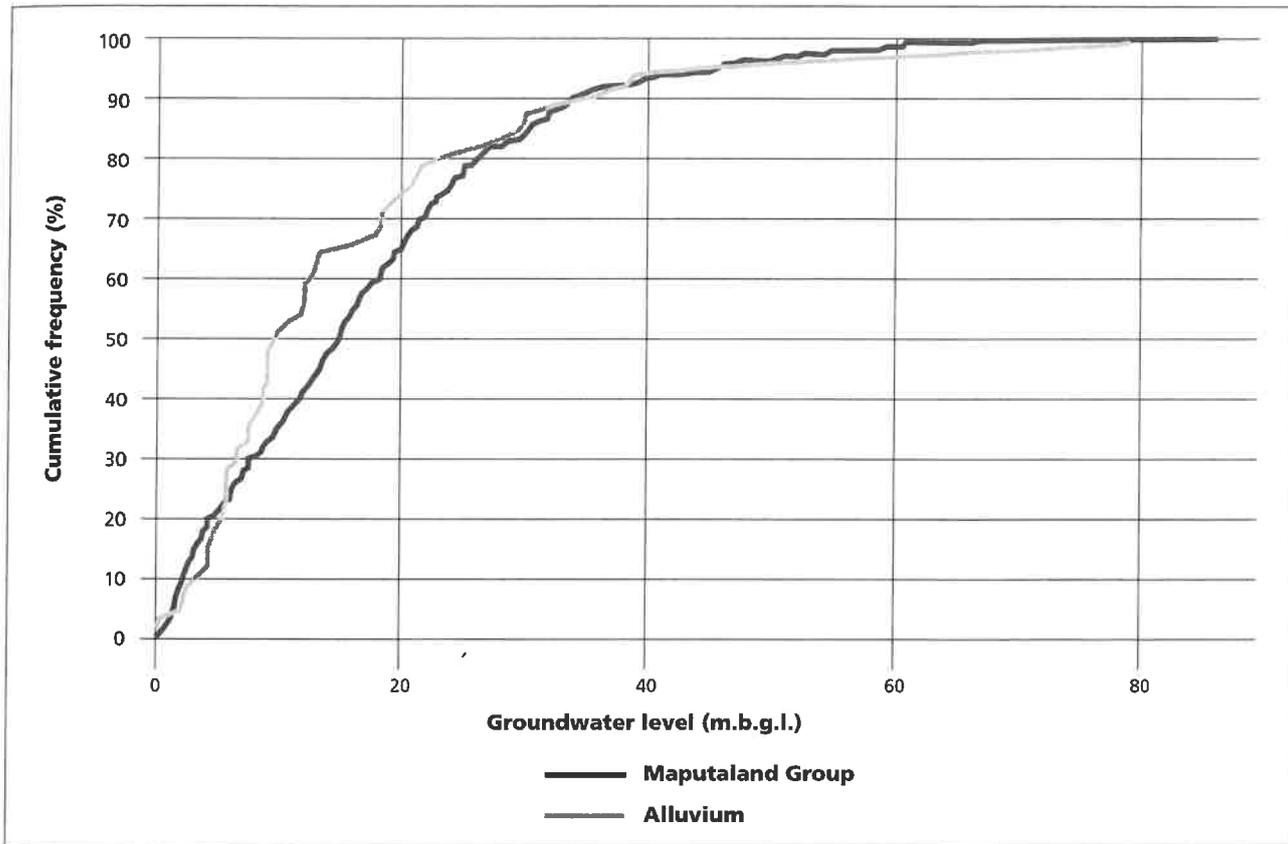
The saturated fine-grained sand comprising the lower portion of the Kosi Bay Formation, and the Uloa and Umkwelane

Formations on which it rests, in the Richard's Bay area, has been found to have combined hydraulic characteristics (Worthington, 1978).

The highest yielding aquifer within the Maputaland Group is the Uloa Formation, which due to its carbonate content behaves similarly to a karstic aquifer. High yields of up to 15 l/s can be easily attained in this aquifer. However, its intermittent occurrence throughout the map area does not allow it to be extensively developed. This aquifer has been identified as intergranular instead of karstic due to the presence of overlying sand, which provide storage for its weathered secondary features. Worthington (1978) found the average hydraulic conductivity, k , for the combined Uloa and Umkwelane Formations to be 4.5 m/day.

Table 4. Hydraulic characteristics of combined Kosi Bay and Umkwelane-Uloa Formations

PARAMETER	RANGE	AVERAGE
Hydraulic conductivity k (m/day)	0.5 – 12	3
Transmissivity T (m ² /day)	4.0 – 70	25
Co-efficient of storage S	0.07 – 0.25	0.15

Figure 7. Groundwater level cumulative frequency plot for intergranular aquifers

Groundwater quality in the Maputaland Group aquifers is usually very good ($EC < 100$ mS/m). Lower EC values do seem to be found along the eastern parts of the coastal plain, probably due to higher rainfall. When plotted on a Piper diagram (Figure 9), the groundwater from the Maputaland Group sands is typical of alkaline water in sandy aquifers, and dissolution and mixing takes place in this dynamic environment. Pit latrines in the sands do not appear to have a significant

effect on the bacteriological quality, due to the good filtering capacity of the sand. This means that from a distance of 5 m from the pit there is often complete bacteria die out. However, more mobile and persistent elements such as nitrate do move considerable distances within the aquifer and are therefore a major impact of on-site sanitation systems on the Maputaland Coastal Plain.

4.2.2 Alluvium (Q)

Coarse sandy alluvium present in major river channels to the south of the area (Durban map) has been found to have a hydraulic conductivity in the approximate range 100 to 150 m/day, and a co-efficient of storage of between about 0.15 and 0.17. The median yield of successful boreholes in alluvium can be expected to be 1 l/s. It can be seen from Figure 7 that the groundwater levels in alluvium are relatively

shallower than those in the Maputaland Group aquifers. From the borehole data available there was not enough complete chemical analyses to construct a Piper diagram to depict the characteristics of groundwater derived from alluvium. Due to constraints of the main map scale, most of the alluvial aquifers are not shown.

Figure 8. Yield frequencies of boreholes in intergranular aquifers (117 and 239 boreholes analysed respectively for alluvium and Maputaland Group)

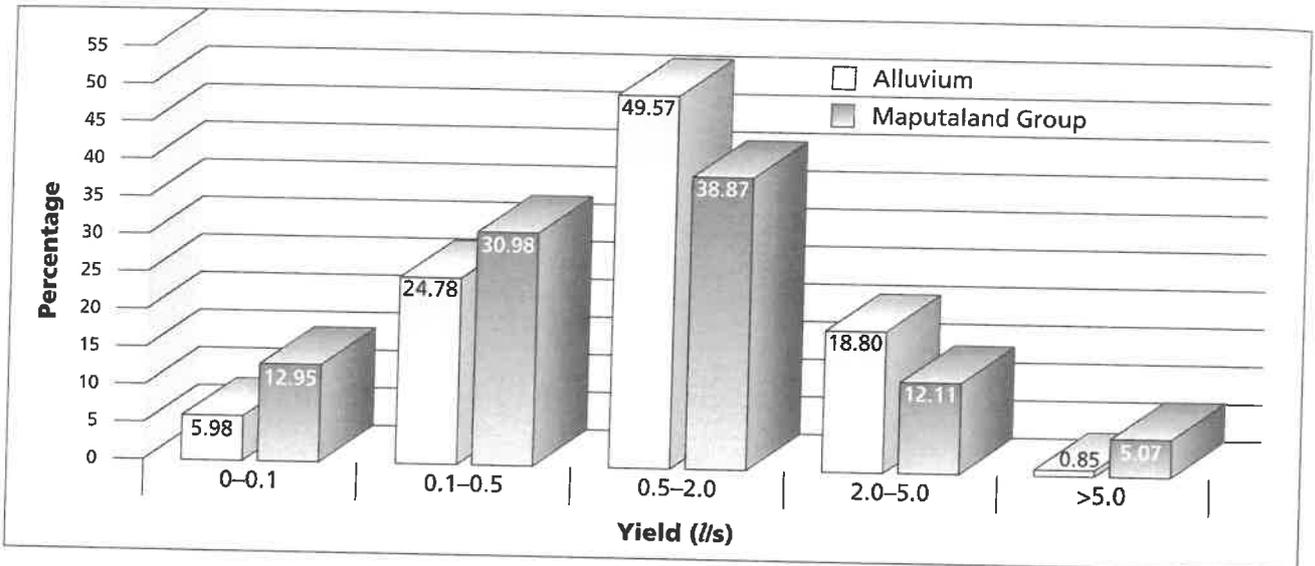
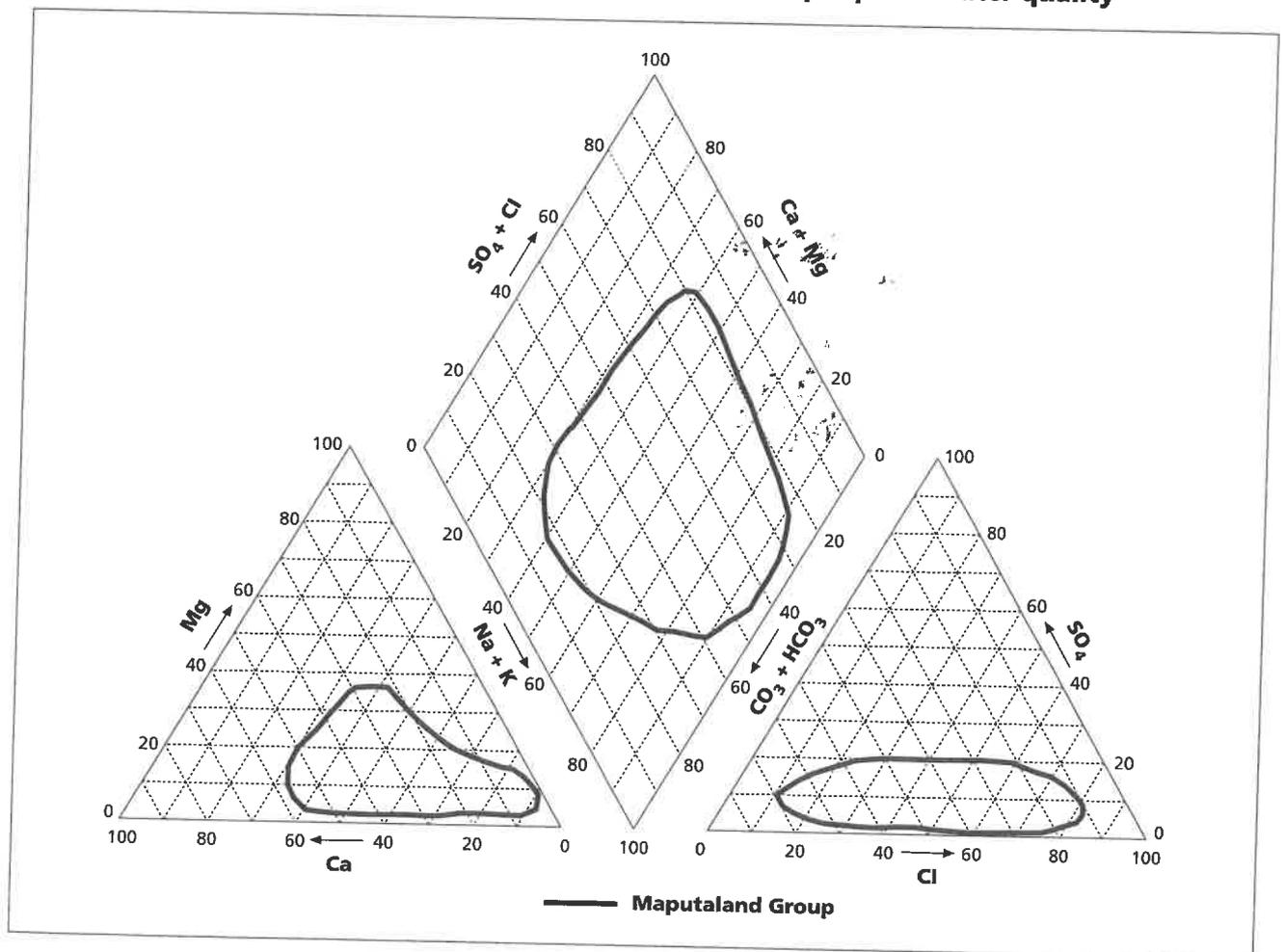


Figure 9. Composite Piper diagram of Maputaland Group aquifer water quality



4.3 Fractured aquifers

Rocks that behave in a brittle manner upon fracturing and have limited or no secondary intergranular properties have been grouped as fractured aquifers. Rock fracturing has its greatest expression in the faults along the coastal zone, thereby including the Natal Group and Dwyka Group. Jointing in these rocks is far more common than faulting. The above mentioned rocks respond favourably to tectonic and other

tensional forces and fracturing occurs because their competency tends to allow the joints and fractures to remain open. Dolerite intrusions into these rocks are also not very common because of their lack of discontinuities, which would allow for extensive intrusions. A few dolerite sills do occur, but dolerite dykes are more common as feeder structures to intrusions into the argillaceous sediments above.



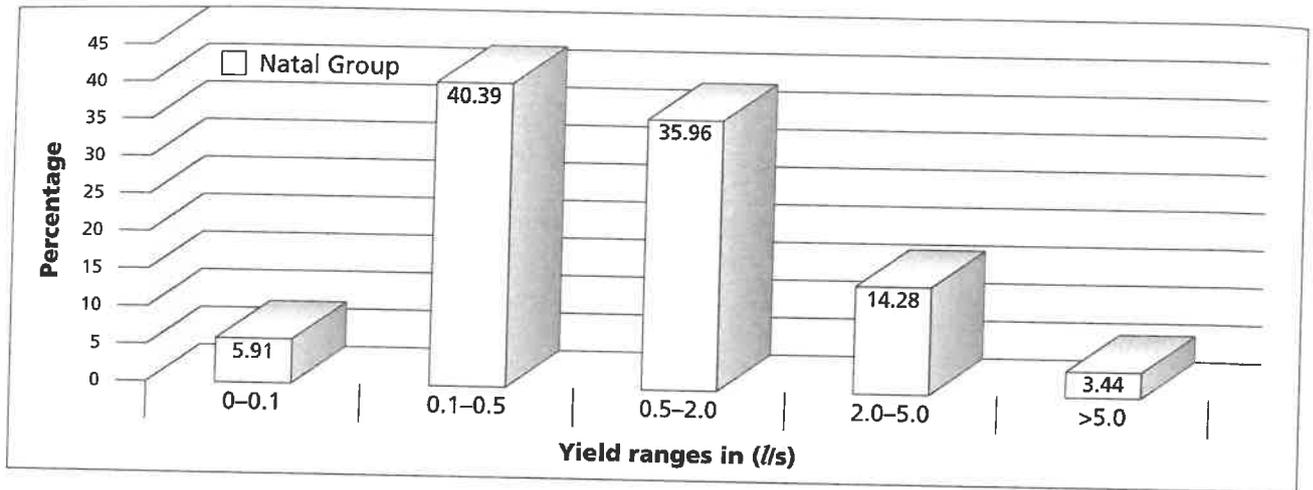
Plate 1. Sandstone of the Natal Group. Jointing and fracturing are common features in these competent sandstones. Jointing, fracturing and bedding planes are usual drilling targets. The median yield value for this unit is 0.5 l/s. (Photograph: P.S. Meyer).

4.3.1 Natal Group (On)

The Natal Group sandstones have a high quartz content, which causes them to behave in a brittle manner. These rocks usually have well-developed joints that may be interconnected. Fault zones are very important high yielding features in these rocks. The faults may be silicified which decreases their transmissivity and thus restricts its yield. These sandstones have a higher yield than neighbouring lithologies because of their ability to transmit larger amounts of groundwater. Measured hydraulic conductivities ranges from 0.4 – 7.7 m/day and the storativity is estimated to be 5%. The median borehole yield in the Natal Group is 0.5 l/s, with yields consistently being between 0.1 and 2 l/s (Figure 10). A drilling success rate of

between 80 and 90% is commonly achieved with scientifically sited boreholes.

The quality of groundwater from the Natal Group is usually very good. Elevated electrical conductivity (above 70 mS/m) is not to be expected unless pollution of the aquifer has occurred. Groundwater from the sandstones have been reported to be chemically aggressive and have high iron and manganese contents. Figure 12 shows the groundwater to be a calcium, magnesium bicarbonate type water which is characteristic of a recently recharged groundwater. The chemical characteristics of the Natal Group are similar to the Dwyka Group.

Figure 10. Yield frequencies of boreholes in the Natal Group (203 boreholes analysed)

4.3.2 Dwyka Group (C-Pd)

The Dwyka Group diamictites are not considered high potential aquifers. Low yields are prevalent because the rock has a storativity of less than 1.5% (this value is considered by some experts as too high) and low hydraulic conductivity. Its massive, structureless nature limits the number of groundwater targets available. However, large scale fracturing of the diamictite in isolated localities has provided areas where yields of up to 10 l/s can be obtained. These high yields are rare and the average borehole yield expected of this fractured aquifer is 0.1 l/s. Fault zones and dolerite contacts are found to have a transmissivity value of 200 – 400 m²/day. (Martinelli *et al*, 1994). Many of the fractures may be kaolinised thereby decreasing the potential yield. A success rate of 30 – 40% confirms this aquifer's poor status.

In the Ulundi area, the contact between the Dwyka Group and the underlying Natal Group has been found to be a potentially high-yielding aquifer. Transmissivity values averaging 30 m²/day and storativity values of less than 0.01% have been

calculated from pumping tests. The borehole yields range from 1 – 8 l/s. If groundwater is to be sought from ground overlain by Dwyka Group rocks, it is suggested that where there is no well-defined fault or fracture, boreholes should target the underlying Natal Group contact zone, provided the contact is less than 100 m deep.

The quality of groundwater derived from the Dwyka Group is usually good, i.e. suitable for human consumption. The electrical conductivity can range from between 8 to 347 mS/m but averages 70 mS/m. Groundwater along the coastal zone may be more saline, with values commonly reaching 300 mS/m but this decreases inland. There are no other water quality variables that pose any threats to the groundwater quality in these aquifers. Groundwater from the Dwyka Group is characterised as being a sodium, chloride, potassium bicarbonate water. However, along the coastal zones, the groundwater from this aquifer can be characterised as a calcium, sodium, chloride type water (Figure 12).

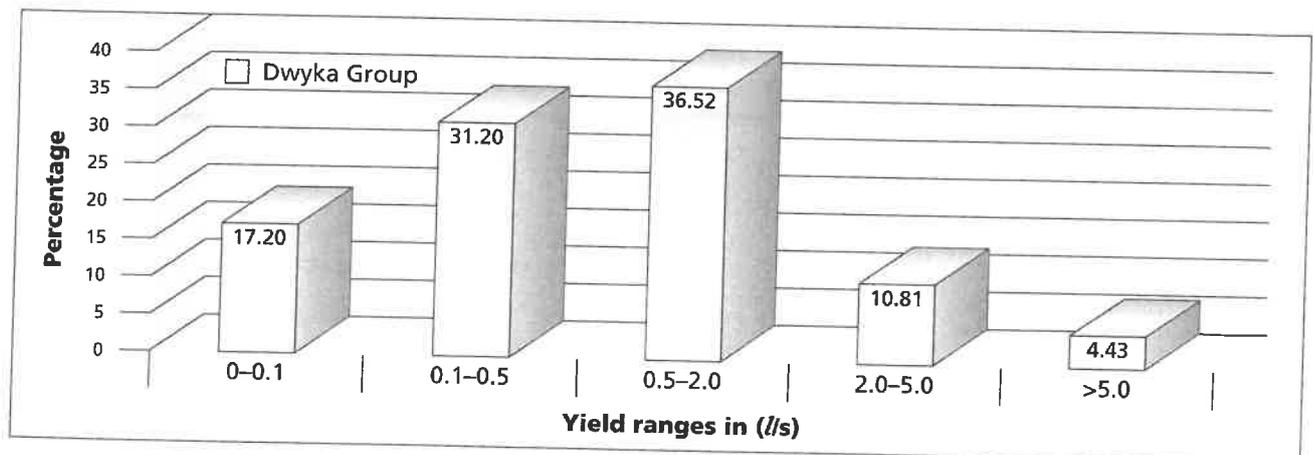
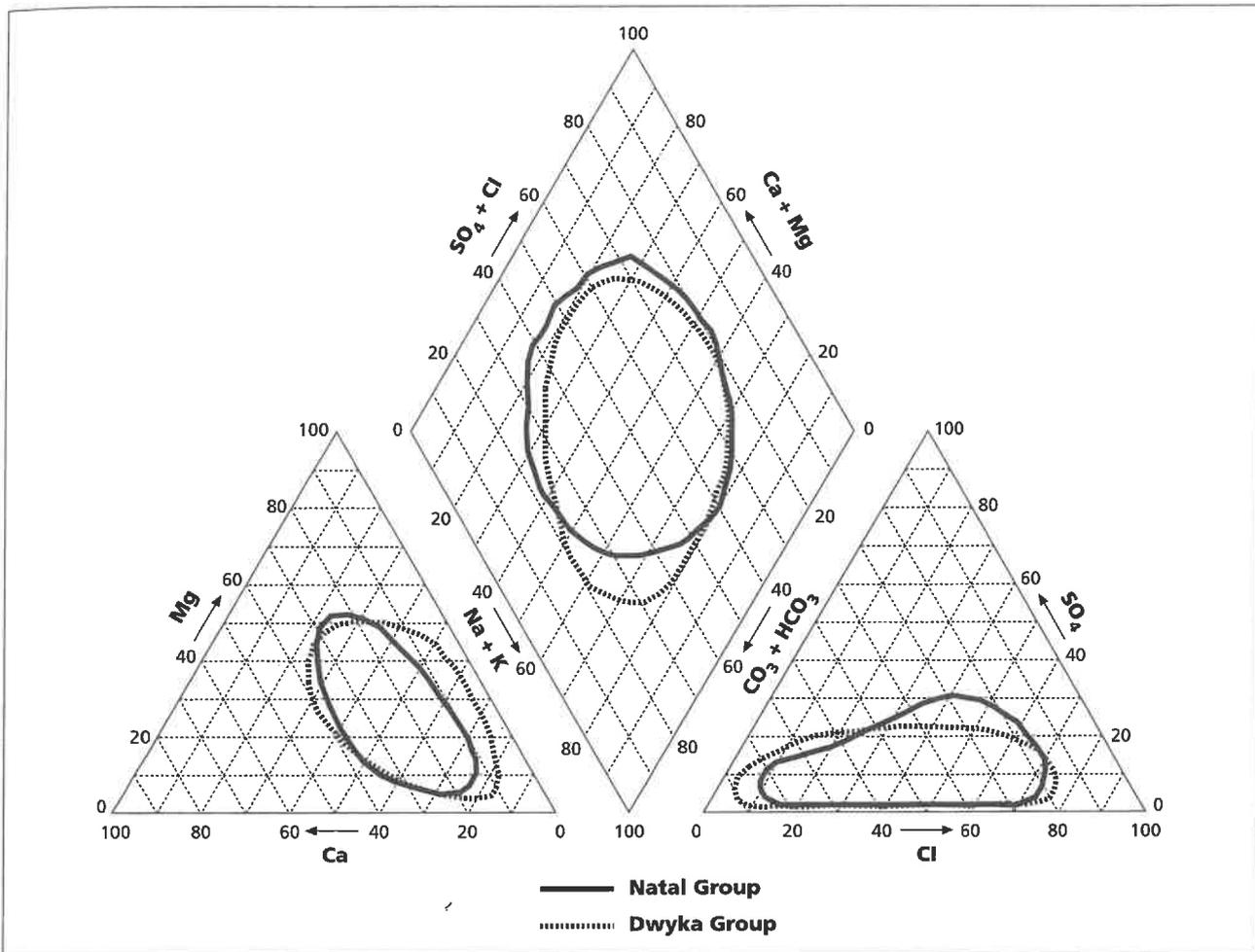
Figure 11. Yield frequencies of boreholes in the Dwyka Group (564 boreholes analysed)

Figure 12. Composite Piper diagram of fractured aquifers

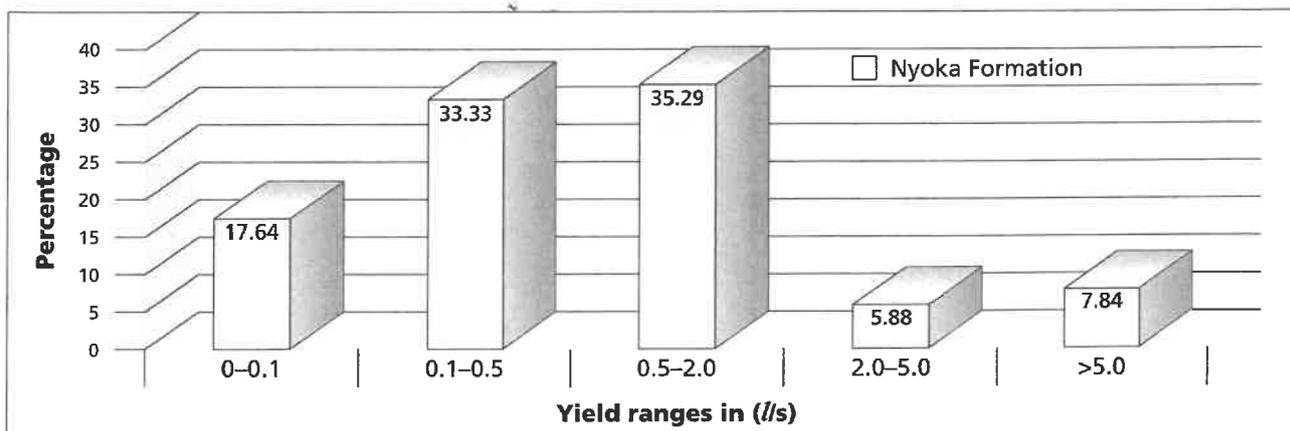


4.3.3 Nyoka Formation (Trn)

Hydrogeological data for the Nyoka Formation is limited due to its scant distribution. However, from the 51 borehole records on the database, it was established that the yield characteristics are quite similar to those from the Natal Group. Most of the

successful boreholes yield between 0.1 and 2 l/s (Figure 13). No groundwater quality data were available for analysis from boreholes in this formation.

Figure 13. Yield frequencies of boreholes in the Nyoka Formation (51 boreholes analysed)



4.4 Intergranular and fractured aquifers

4.4.1 Nondweni Group (Zw)

The limited extent of these rocks only provided two borehole records that intersected this intergranular and fractured aquifer. Both yields were greater than 0.5 l/s. The ground-

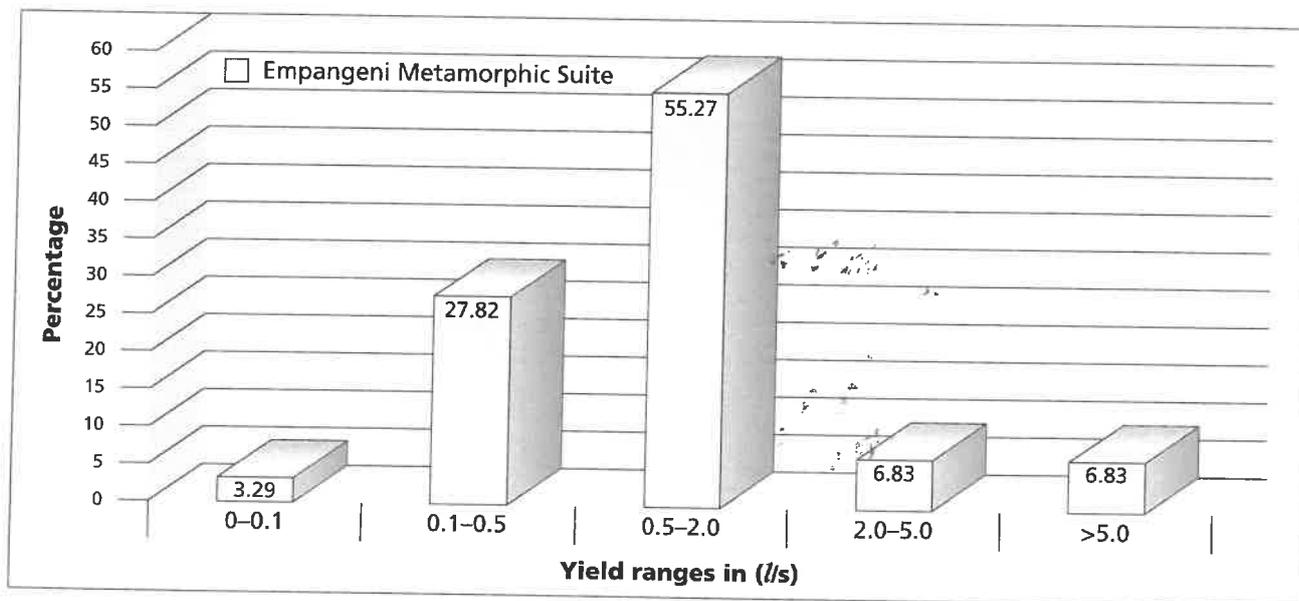
water quality data for the boreholes ranges considerably. The EC ranges from 23 – 205 mS/m, with sodium and chloride contributing to the high salinity.

4.4.2 Empangeni Metamorphic Suite (Zi)

The 29 boreholes drilled into these metamorphic rocks produced groundwater with a median yield of 0.8 l/s. Figure 14 shows over 50% of boreholes yielded between 0.5 and 2 l/s. Weathering of the metamorphosed rocks resulting in intergranular conditions, which act as storage for the underlying

fractures, is considered the most likely hydrogeological explanation for the occurrence of groundwater. No specific characterisation work has been conducted on these aquifers. However, from limited data, it appears that the groundwater potential of these rocks is moderate.

Figure 14. Yield frequencies of boreholes in the Empangeni Metamorphic Suite (29 boreholes analysed)



4.4.3 Barberton Supergroup (Zr)

No boreholes with yield data were available for analysis in this group of rocks. The yield of successful boreholes is expected to be between 0.5 and 2 l/s.

4.4.4 Mozaan and Nsuze Group (Rm and Zn)

The Mozaan and Nsuze Group rocks have mostly fractured aquifers associated with them, although occasionally they do have weathering profiles of more than 25 m in depth. The borehole yields in these rocks are mostly between 0.5 – 2 l/s (Figure 15). Limited good quality hydrogeological data are available for aquifers in the Mozaan and Nsuze Groups, thus

it is recommended that further hydrogeological exploration be conducted in these rocks. The groundwater quality data from the few boreholes with chemical analyses indicate that the groundwater is a sodium, magnesium bicarbonate water, characteristic of alkaline groundwater from crystalline areas (Figure 18).

Figure 15. Yield frequencies of boreholes in the Mozaan and Nsuze Groups (60 boreholes analysed)

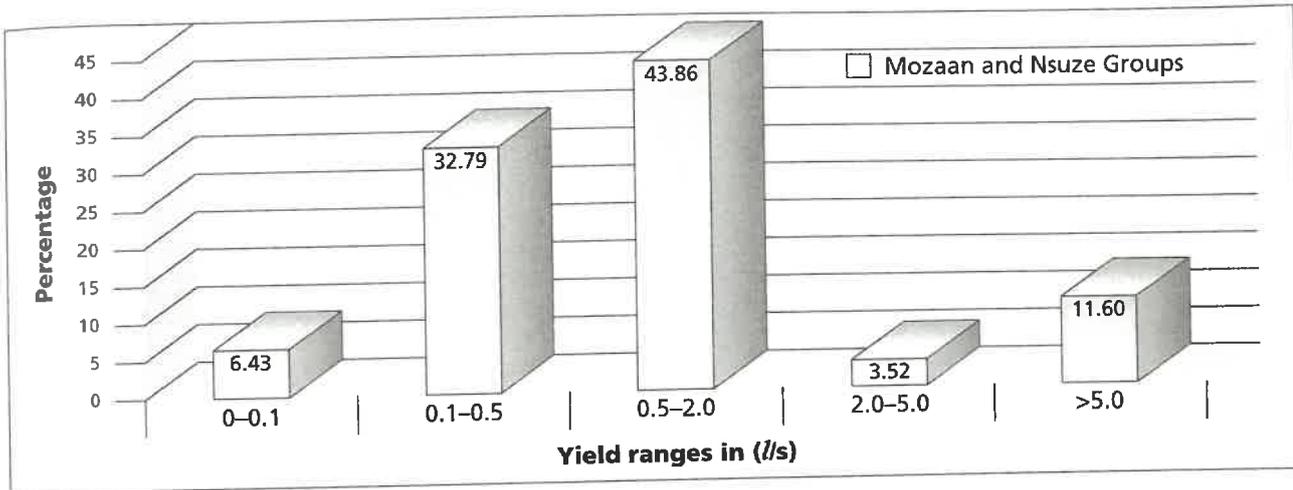


Plate 2. Highly decomposed basic crystalline rocks of the Nsuze Group east of Paulpietersburg. Weathering in these rocks plays an important groundwater role, as zones of weathering and underlying fractures are often targets for groundwater development. Borehole yields generally range between 0.5 and 2 l/s. (Photograph: J. Girman).



Plate 3. Intrusive porphyritic granite of the Mozaan Group north of Paulpietersburg shows a typical weathering profile. The weathered zone effectively stores and transmits water to the deeper fractured zone. (Photograph: P.S. Meyer).

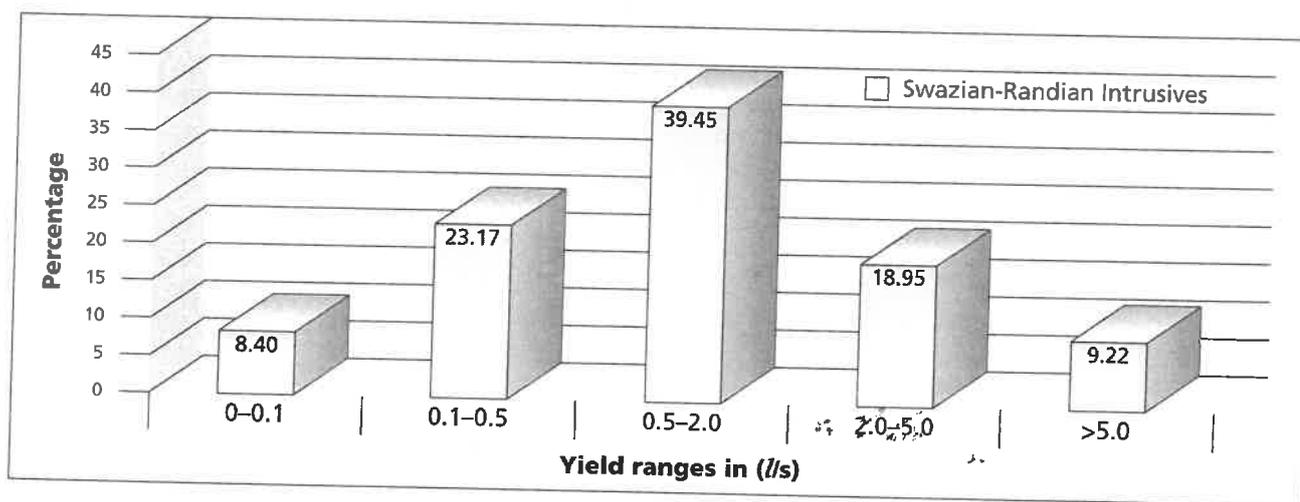
4.4.5 Z-R Intrusives (Z-Rg)

The granite and granitic gneiss rocks, which are the predominant type of lithology of these intrusive rocks, have the typical weathering profile of crystalline rock formations. The weathered profile extends to average depths of 20 – 30 m. This weathered zone imparts an intergranular property to the weathered material that effectively stores and then transmits infiltrating water to fracture zones in the deeper unweathered parts of the rock. From records obtained from the NGDB, yields of successful boreholes are expected to be mostly between 0.5 and 2 l/s, with a median value of 0.8 l/s. The bottom of the weathered zone, at its contact with the harder unweathered rock, often has seepage or low yielding water strikes. The low

yield is due to the relatively low hydraulic conductivity of this zone, which restricts the flow of groundwater into the borehole. Drilling boreholes deeper than the weathered zone is recommended so as to improve chances of striking a fracture, which will be more likely to yield economical quantities of groundwater.

Groundwater quality records for these aquifers could not be isolated from the data contained in the Pongola Supergroup dataset. However it is expected that the groundwater character will be that typical of groundwater from crystalline areas, similar to the Natal Metamorphic Province (Figure 18) namely sodium, magnesium bicarbonate water.

Figure 16. Yield frequencies of boreholes in the Swazian-Randian Intrusives (142 boreholes analysed)

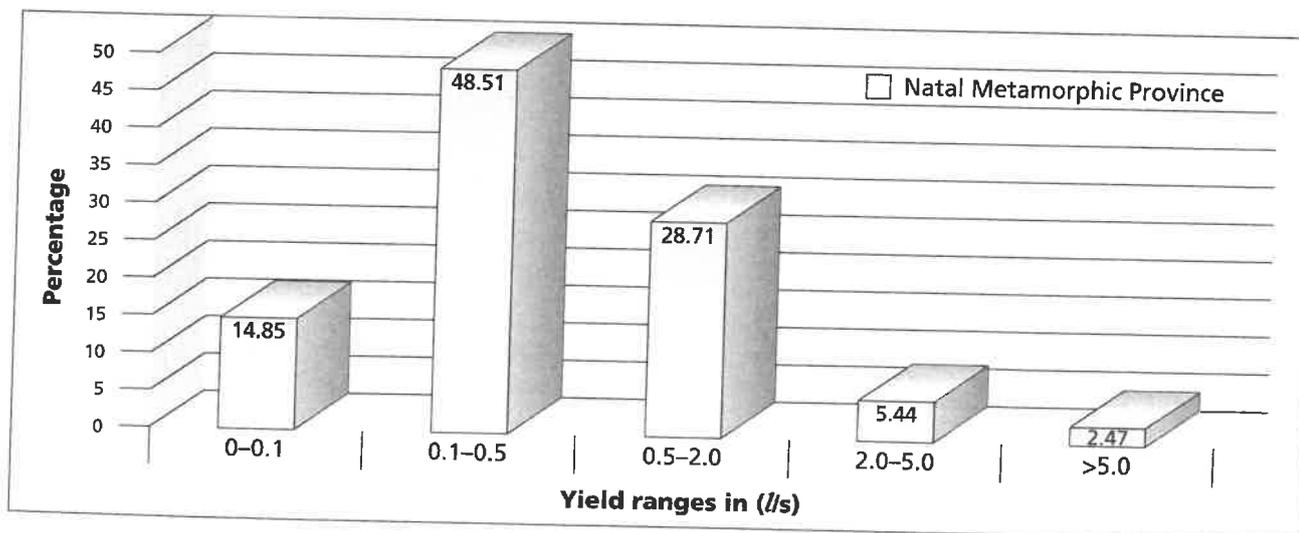


4.4.6 Natal Metamorphic Province (Nmp)

The occurrence of groundwater in the predominantly crystalline rocks of the Natal Metamorphic Province is associated with fracturing, near surface weathering processes and

diabase intrusions. It is, however, the fractures that offer the highest yields as these are often well supplied with groundwater from overlying clayey intergranular zones produced by

Figure 17. Yield frequencies of boreholes in the Natal Metamorphic Province (202 boreholes analysed)

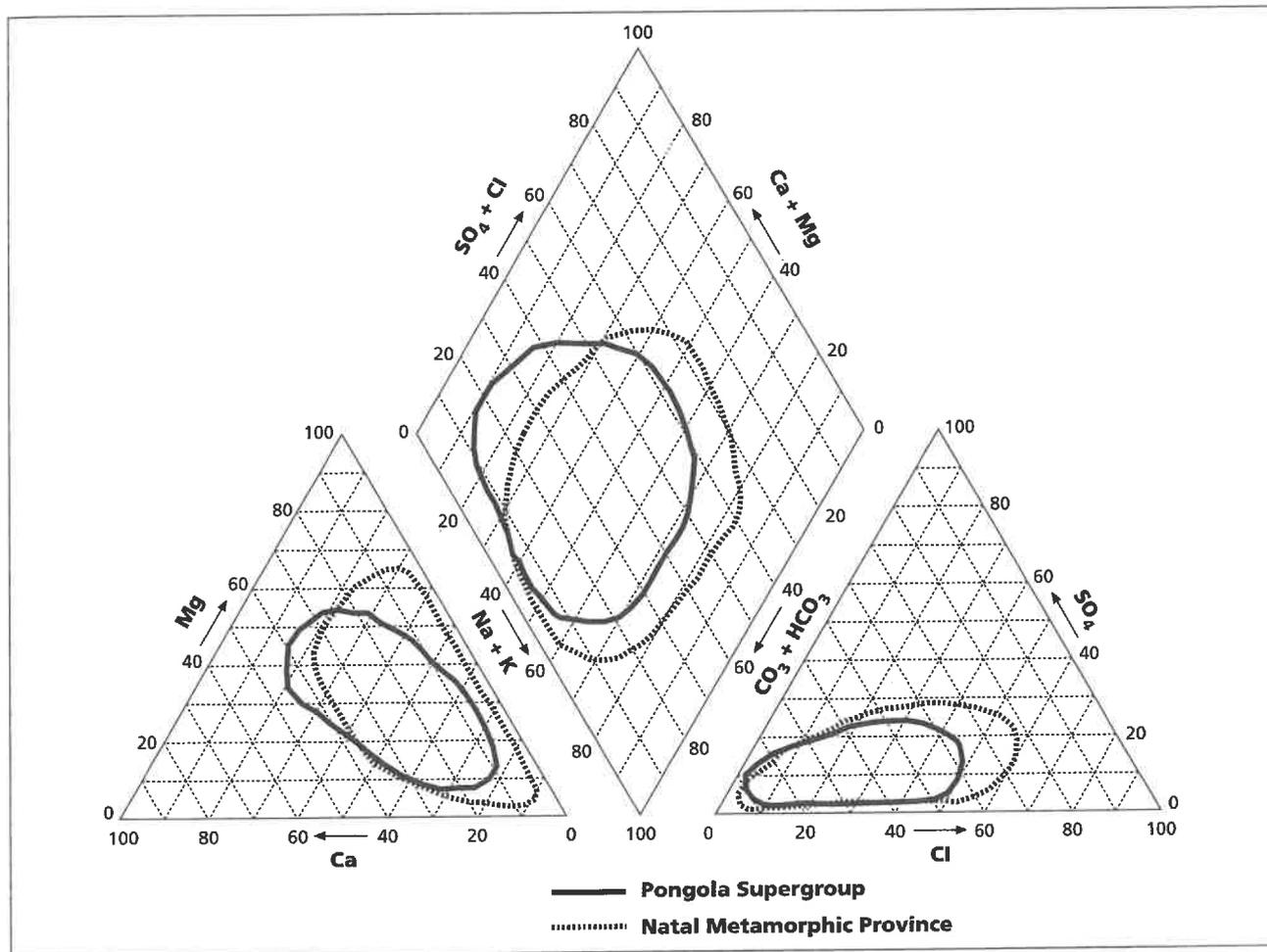


weathering. Weathering of the rock results in a material that has a high porosity but low hydraulic conductivity due to the clay content derived from the feldspars. Generally, the weathered, intergranular zone is in hydraulic contact with the underlying fractured or solid bedrock. Hence, a borehole drilled below the intergranular zone will draw from the storage above. Analysis of the occurrence of faults shows the Natal Metamorphic Province to have the highest incidence of faults (King, 1997). The susceptibility of these Basement rocks to fracturing is probably because of their brittle nature and greater age, which has exposed it to more tectonic activity, compared to the more ductile argillaceous rocks. Expected

borehole yields within the intergranular zones are typically between 0.1 and 0.4 l/s, whereas in underlying fractures, yields greater than 0.5 l/s can be realised. The overall median yield (0.3 l/s) in these aquifers is usually less than in surrounding sedimentary rocks. Figure 17 shows a graph of yield frequencies.

The sodium, calcium, magnesium bicarbonate water character of the groundwater is typical of alkaline groundwater from crystalline areas (Figure 18). The general quality of the groundwater is normally very good, with only fluoride values of about 2 mg/l sometimes found in argillaceous metamorphic rock aquifers.

Figure 18. Composite Piper diagram of basement intergranular and fractured aquifers



4.4.7 Karoo Supergroup sedimentary rocks (Pe and P-Trb)

As illustrated in the chapter on geology, a number of geological formations with similar hydrogeological properties have been grouped together within the Karoo Supergroup. The Vryheid Formation has been given the same symbol on the map as the rest of the Karoo Supergroup sedimentary rocks, i.e. Pe, even though it has a distinct arenaceous character which is depicted as such on the hydrogeological map. The Vryheid Formation is discussed separately from the other Eccca Group Formations in this section due to their hydrogeological differences. It is worth noting that the Vryheid Formation has the

largest surface distribution of all the rock types on this hydrogeological map (12 388 km²), and therefore has greater significance to the hydrogeology of the mapped area.

Median borehole yields in the arenaceous Vryheid Formation rocks are 0.6 l/s. Water strikes are mostly encountered in fractured rock, however weathering at the contact between sandstone and shale within the Formation also yields groundwater. Very limited to no primary porosity exists in the sandstone due to strong cementing between grains, even though the sediments are often coarse-grained.

Fractures within the argillaceous rock mass usually constitute reasonable aquifers, capable of yielding in excess of 0.2 l/s. Fractures within the more fine-grained rocks may tend to close once they have been dewatered due to the ductility of the rock. A slightly lower median of 0.5 l/s can be expected of these aquifers (Figure 19).

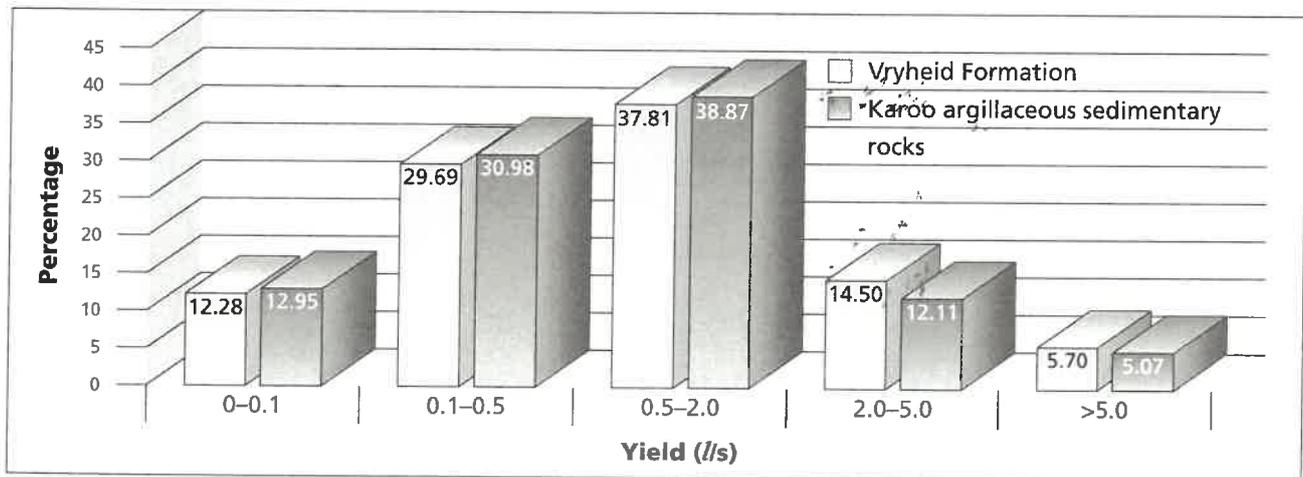
Hydrogeological characteristics of Karoo Supergroup sedimentary rock aquifers are variable. Transmissivity values of between 0.5 – 150 m²/day have been determined from boreholes in the Vryheid Formation in the Nongoma area (Martinelli *et al*, 1994). A shale-sandstone contact within the Vryheid Formation in the Hlobane area was found to have a transmissivity of 34 m²/day, and a transmissivity of 110 m²/day at the dolerite-sandstone contact. In the Newcastle area, the Vryheid Formation was found to have an average transmissivity of between 10 – 30 m²/day, with productive zones rarely exceeding 50 m²/day. This variability is due to the complex relationship between fractures, intergranular zones and the matrix within the sedimentary geological materials.

EC of groundwater in the Vryheid Formation ranges from 4 – 636 mS/m, with an average of 81 mS/m. The quality of groundwater from the argillaceous rocks is generally worse with EC ranging from 3 – 1097 mS/m, and averaging 113 mS/m. The groundwater is usually high in sodium, chloride and magnesium, which typifies dissolution environments (Figure 23).



Plate 4. Sandstone of the Vryheid Formation (Ecca Group) in the Mooi River Valley. The Vryheid Formation is widely distributed in the map area. Water strikes are encountered in fractures, joints and on bedding planes, and the median yield value for this unit is 0.6 l/s. (Photograph: J. Girman).

Figure 19. Yield frequencies of boreholes in the Karoo Supergroup (1034 and 355 boreholes analysed respectively for Vryheid Formation and argillaceous rocks)



4.4.8 Lebombo Group (Jl)

The two Formations comprising the Lebombo Group, namely the Jozini and Letaba Formations, are considered low to medium potential aquifers. Possible groundwater target zones include lava flow contacts, buried weathered surfaces, fractures and Rooirand dolerite swarm contacts. Groundwater yields of between 0.1 and 2.5 l/s can be obtained from boreholes sited scientifically. The static groundwater levels are highly variable, probably a result of compartmentalisation by the dolerite dyke swarm. Springs are fairly common on the eastern slopes of the Lebombo mountain range.

Groundwater quality is highly variable as demonstrated by the fact that potable water can be found within 300 m of a

borehole with unsuitable water quality. Elevated chloride and fluoride usually influence the quality of groundwater emanating from these formations. Average EC for the basalt (Letaba Formation) is 170 mS/m, and 140 mS/m for the rhyolite (Jozini Formation). The fluoride values are high, making the water unsuitable for long-term human use, unless treatment or dilution with another source of water is practised. The Piper diagram in Figure 21 shows the characteristics of the groundwater from the two formations to be quite similar. They both reflect high sodium, chloride bicarbonate characteristics, which typify alkaline groundwater in crystalline areas.

Figure 20. Yield frequencies of boreholes in the Lebombo Group (146 and 408 boreholes analysed respectively for Jozini and Letaba Formations)

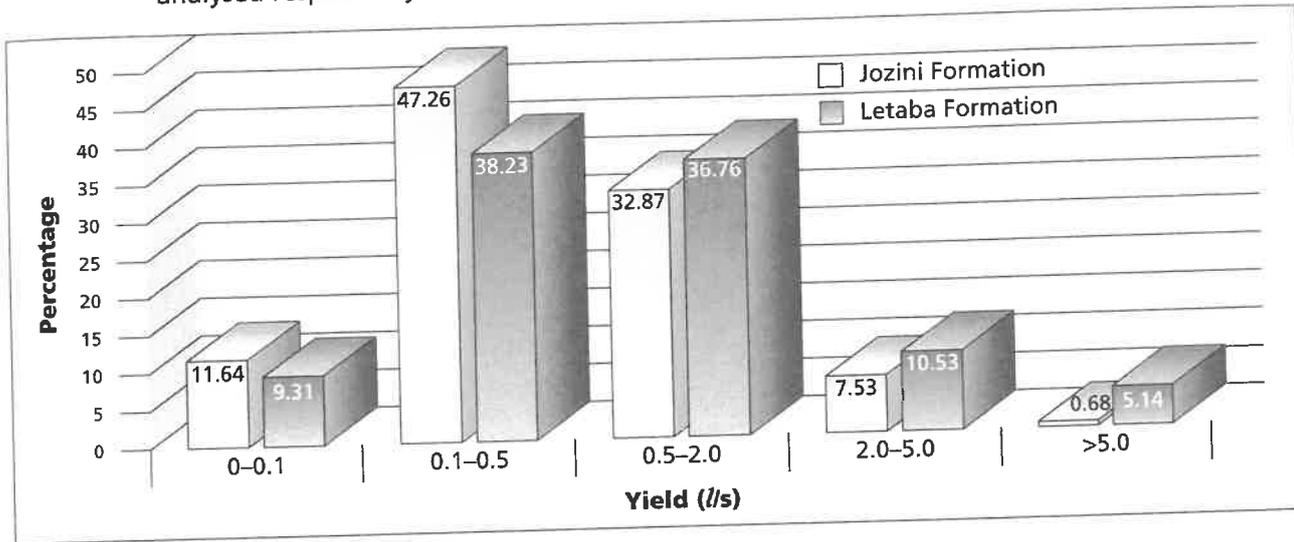
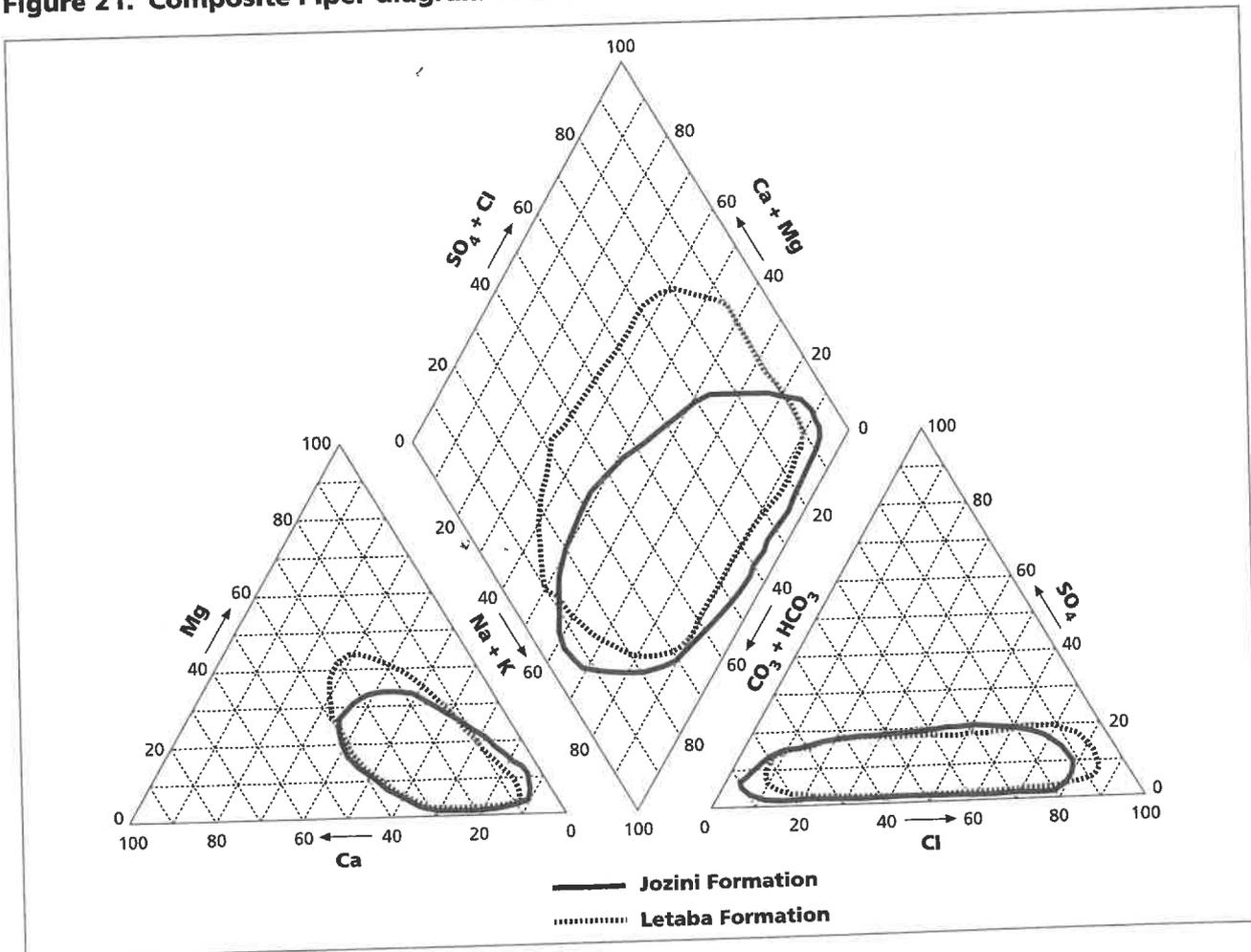


Figure 21. Composite Piper diagram of Lebombo Group intergranular and fractured aquifers



4.4.9 Karoo Dolerite (Jd)

A number of different possible groundwater targets or aquifers occur in dolerite. Fractured and weathered dolerite rock itself not only constitutes an aquifer, but also its contact with the host rock into which it has intruded. The process of dolerite intrusion has resulted in geological features that have the potential to bear water. Intrusion of dolerite, by means of sills

and dykes, causes induration of the contact with its host rock and displacement of rocks around the intrusion, thus increasing the hydraulic conductivity of the zone. The yield associated with contacts with other rocks types varies considerably and is dependent on fracture interconnections. Dolerite contacts with competent rocks such as Natal Group sandstone

Figure 22. Yield frequencies of boreholes in Karoo dolerite (625 boreholes analysed)

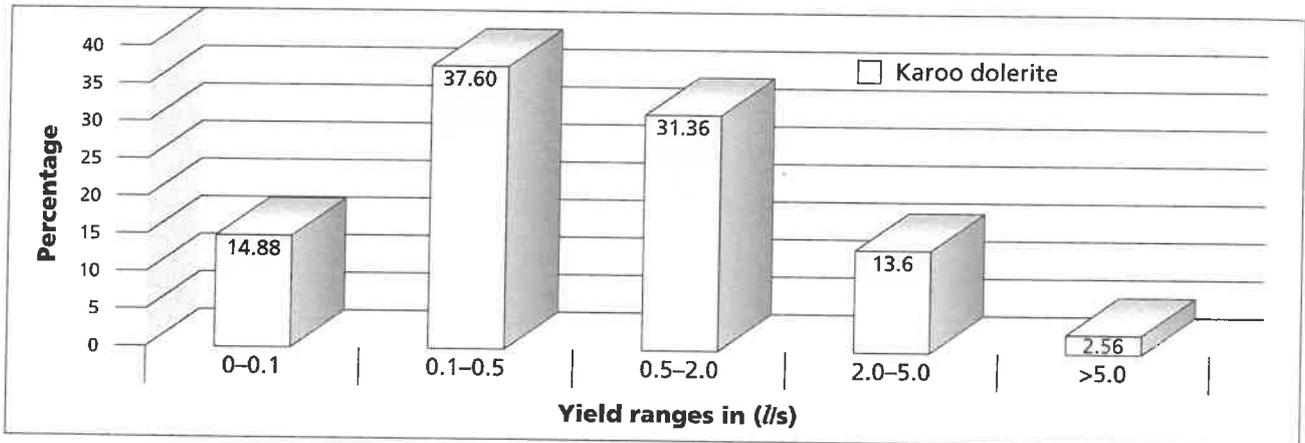


Figure 23. Composite Piper diagram of intergranular and fractured Karoo Supergroup aquifers

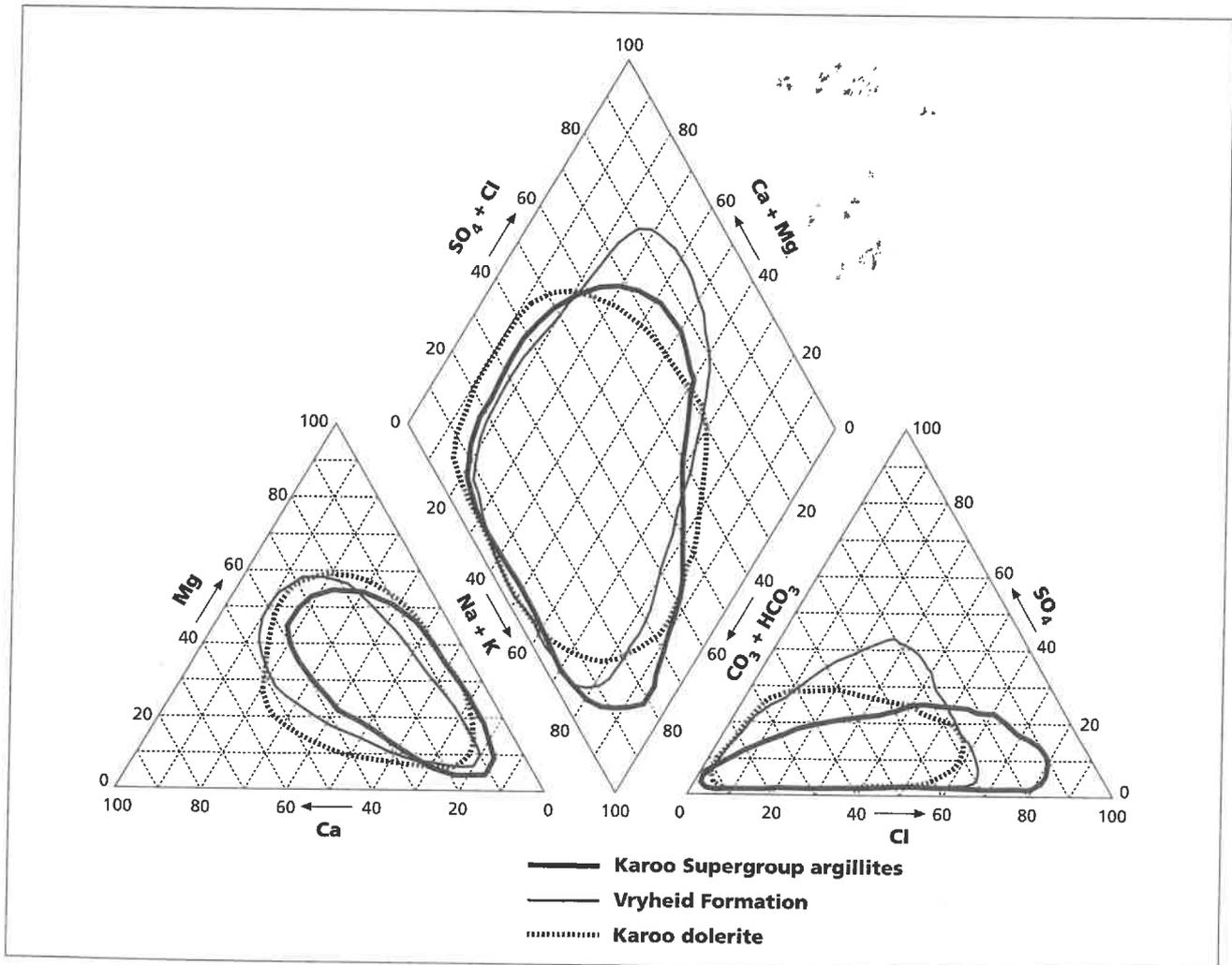




Plate 5. Typical weathering and jointing in a thick dolerite sill north of Tugela Ferry. Prominent vertical joints in the sills, as well as sill contact zones with sedimentary rocks can be targeted for groundwater development. (Photograph: P.S. Meyer).



Plate 6. A fractured and jointed zone on the contact of a dolerite dyke with the Vryheid (sandstone) Formation, south of Tugela Ferry. These contact zones are common drilling targets. (Photograph: P.S. Meyer).

and granitic basement rock are found to have higher yields than those contacts with argillaceous rocks (King, 1997). Typical borehole yields from successful contact zones can range from 0.2 l/s for argillaceous contacts to 1.4 l/s for arenaceous or crystalline contacts. Water strikes can occur either at the top contact or bottom contact of dolerite sills. There is no fixed rule as to which is the better target.

Apart from dolerite's contacts with host rocks, the dolerite body may be weathered and also fractured. In the humid conditions of KwaZulu-Natal, weathering of dolerite intrusions to corestones and eventually, deep red clay is common. This fine-grained intergranular material acts as a type of "sponge" in storing groundwater and transmits it to areas of higher hydraulic conductivity, such as contacts or underlying fractures. Fractures in fresh dolerite tend to be well defined due

to the brittle nature of the rock. This often ensures that the fractures will commonly yield in excess of 0.5 l/s. The median yield of dolerite associated aquifers is 0.4 l/s, which is supported by the yield frequency plot in Figure 22. It must be highlighted that the interconnected relationship between the dolerite's intergranular zone with underlying fractures may increase the potential yield of the aquifer. There is a 70–80% chance that boreholes drilled into dolerite will yield groundwater.

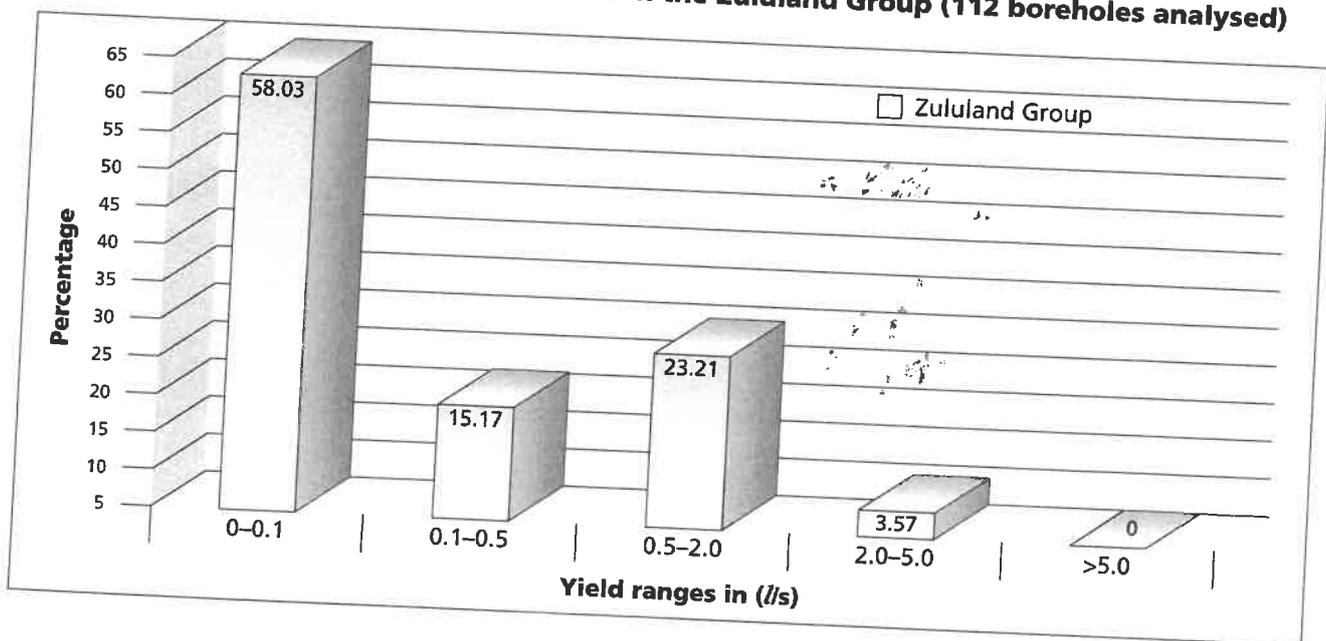
The Piper diagram shows groundwater from dolerite aquifers to be of the recently recharged bicarbonate, calcium, magnesium type (Figure 23). EC of the groundwater may sometimes be greater than 90 mS/m. Elevated concentrations of sodium, chloride, magnesium and calcium may be found in areas of lower rainfall.

4.4.10 Zululand Group (K-Tu)

The rocks of the Mzinene and St Lucia Formation are notoriously poor aquifers. In fact they may be regarded as aquicludes. The few boreholes drilled into these rocks have yields generally less than 0.1 l/s (Figure 24). The groundwater quality from

these rocks is highly saline (EC > 800 mS/m). The conglomerate of the Makatini Formation is the only formation that may yield up to 0.4 l/s, however groundwater, as from the rest of the group, will be saline.

Figure 24. Yield frequencies of boreholes in the Zululand Group (112 boreholes analysed)



4.5 Regional water levels

The depths of the groundwater below ground level in the map area are variable and are influenced, inter alia, by locally prevailing topographic conditions. In dissected terrains with steep slopes, the groundwater level depth is extremely localised and variable, but in flatter terrain, as in the interior river basins and Maputaland Coastal Plain, definable groundwater levels exist. In many boreholes, groundwater struck at depth (e.g. 40 m) rises to a much shallower piezometric level (e.g. 20 m) in the borehole due to confining pressures. Groundwater rest levels in boreholes in the region are in the range of

0 to 110 m below ground level, the overall median rest level in the inland areas is 20 m. The Newcastle area exhibits a very shallow groundwater level, where the median depth of groundwater in the Karoo rocks is 10 m. In the same rocks in the drier and more dissected areas to the east the groundwater levels increase to 30 m

On the Maputaland Coastal Plain intergranular aquifer groundwater is usually struck in the depth range of 5 to 30 m. The shallow groundwater level is accessed by numerous hand-dug shallow wells, described in Chapter 5.

Artesian flow of groundwater from boreholes in the region is uncommon. Usually such flows are associated with borehole sites that are controlled by extensive, higher-standing aquifer recharge areas from which the artesian head of a few centi-

metres above ground level is derived. Artesian flows where they do occur are very low, in the approximate range of less than 0.1 l/s to 1 l/s.

4.6 Regional groundwater quality

4.6.1 General trends

Groundwater quality in the region covered by the Vryheid hydrogeological map sheet is variable, but it is in general good, with electrical conductivity values (EC) of less than 100 mS/m being present in most areas. Poorer quality, more saline, groundwaters are generally associated with those portions of the map area that have a relatively lower rainfall (Lebombo Group, parts of the Karoo Supergroup sedimentary rocks), such as between Ulundi and Empangeni. The marine sediments of the Zululand Group (Cretaceous) that underlie the Maputaland Coastal Plain generally contain highly saline groundwater (EC > 800 mS/m) in the few places where groundwater has been encountered in boreholes drilled. A map depicting electrical conductivity of groundwater is included as an inset map on the General Hydrogeological Map sheet.

The range and average values of measured electrical conductivity of the groundwater occurring in the various hydrogeological units in the area covered by the hydrogeological map is given in Table 5. Note that some units are not included due to a lack of chemical data.

The pH value of the groundwater in the various hydrogeological units varies in the range 4,5 to 9,0, but the pH value of most groundwaters is in the range 7,0 to 8,3. Low values of pH, which can be as low as 2,0, are associated with the near-surface, low EC groundwater of peat swamps that occur in

places on the wetter portions of the Maputaland Coastal Plain. High pH values are often associated with saline groundwater in the low rainfall portions.

Dissolved iron (Fe) and manganese (Mn) may be present in significant amounts in some groundwater, including in some cases shallow perched water tables, and in carbonaceous shale of the Karoo Supergroup. Iron concentrations can reach levels up to 40 mg/l, although they usually do not exceed 5 mg/l.

Nitrate (NO₃) levels in groundwater in the area range between 0 – 32 mg/l (calculated as N) but are mostly less than 1 mg/l. The higher values usually reflect the effects of some form of pollution. Fluoride (F) levels in the groundwater are in the range 0 – 18 mg/l, but generally are also less than 1 mg/l. Fine-grained metamorphic rocks, shales, granitic and basalt aquifers have a possibility of having slightly elevated fluoride levels.

The dominance of the bicarbonate ion in much of the groundwater in the region indicates that recent recharge affects most, if not all, of the prevailing hydrogeological regimes. Groundwater has therefore a relatively rapid turnover or short residence time. The presence of sodium chloride, by contrast, represents the effect of the aquifer material on the groundwater passing through it, although in the coastal areas its presence is also due to maritime influences.

Table 5. Electrical conductivity of groundwater for each hydrogeological unit

HYDROGEOLOGICAL UNITS	ELECTRICAL CONDUCTIVITY mS/m	
	Range	Average
Intergranular aquifers		
Maputaland Group	5 – 200	70
Fractured aquifers		
Natal Group	7 – 449	88
Dwyka Group	8 – 347	70
Intergranular and fractured aquifers		
Natal Metamorphic Province	4 – 503	44
Karoo Supergroup		
– argillaceous units	3 – 1 097	113
– arenaceous units	4 – 636	81
– basalt	55 – 1 480	230
– rhyolite-dacite	22 – 640	122
– dolerite	7 – 435	72

4.6.2 Pollution sources

Potential pollution sources of groundwater in urban areas include industrial facilities such as manufacturers, chemical works, etc., and solid waste disposal sites of various types such as ash dumps, industrial and urban landfills. Many of these sites are monitored by DWAF.

The potential for pollution in the rural areas can not be dismissed. Here, because of faulty or unsatisfactory borehole head-works construction, bacteriological (faecal) pollution frequently gains entrance to the borehole and the aquifer. Similar contamination can also occur from any nearby pit latrine and stock enclosures. Locally, fertilisers used for agricultural production may cause some limited groundwater pollution, especially in respect to nitrate.

Coal mining, in the northwest of the map area, presents a special case. Problems of acid mine drainage (AMD) from mainly worked out non-operational coal mine adits and open cast workings, and acid rock drainage (ARD) from above-surface coal mine discard dumps, exist in varying degrees. Such drainage water can have pH values as low as 2,9 and EC values in excess of 1 000 mS/m. The problem of preventing such contaminated drainage from entering surface streams and groundwater can be suitably dealt with in the case of presently or recently operational mines. This is not the case for older defunct mining operations, some of which ceased operations more than 50 years ago, and have no mitigating measures to prevent pollution.

4.6.3 Aquifer vulnerability to pollution

Intergranular, unconfined aquifers are the most vulnerable to pollution. These types of aquifers often have a shallow groundwater table, within 2 – 10 m of the ground surface, as is the case on the Maputaland Coastal Plain. The relatively high permeability of these sediments and the shallowness of the groundwater level give rise to short travel times of contaminants within the unsaturated zone and aquifer body. The filtering action of an overlying sand layer in case of water carrying bacteria, is thus limited and selective short residence time counteracts the bacteria decaying.

Secondary aquifers are more complex to describe in terms of their vulnerability to pollution. The potential pathways from the ground surface to the aquifer itself are not always clearly defined or recognisable. A description of the most likely route contaminants may take is the best method of hypothesising aquifer vulnerability in fractured and/or intergranular rocks.

The unsaturated or vadose zone overlying secondary, confined or semi-confined, aquifers provides the protection of the underlying aquifer against pollution. The nature of this protection layer is very important when determining vulnerability. The permeability or hydraulic conductivity is influenced by the characteristics of the geological formation, i.e. clay content of unconsolidated material, jointing pattern and fracture frequency in rocks, infilling of fractures and joints. Contami-

nants will take the same travel path to an aquifer, as would normal recharge water. It is thus vital that potentially polluting activities do not take place in areas of known groundwater recharge.

The situation for the majority of the secondary aquifers portrayed on the hydrogeological map is that all the aquifers have the potential to become polluted. Only, a site-specific hydrogeological investigation to determine preferential pathways from the surface to the aquifer will establish how vulnerable to pollution each aquifer actually is. The occurrence of less vulnerable rocks is usually due to their massive or structureless character. An example of a rock type that has a relatively lower vulnerability to pollution is the Dwyka Group diamictite. The exception is when the Dwyka Group diamictite is fractured. These fractures are then the only pathway for contaminants to move down below the surface and thus polluted groundwater is likely to accumulate in these features.

All the factors mentioned above must be taken into consideration when determining aquifer vulnerability. An understanding of the geological nature of the rocks and unconsolidated sediments, recharge, groundwater flow and hydrochemistry will provide information on the vulnerability of aquifers on a local scale and assists in the determination of protection measures.

5 Springs, shallow wells and tube wells

5.1 Common springs

The average yield of springs, which are widespread in the higher rainfall interior portions of the map area, is 0,05 l/s. A maximum yield is usually about 2 l/s. One exceptional spring in Pongola Supergroup rocks adjoining the Swaziland border post at Mahamba, southeast of Piet Retief, has a yield of 7,5 l/s. Spring yields are strongly influenced by seasonal rainfall variations, with the yield of a spring of about 2 l/s in the wet summer months frequently falling to about 1 l/s in the dry winter months. Many springs of very low yield dry up completely in the winter months. A vast number of springs are utilised as a source of domestic and stock watering supply in the rural areas. The most favourable locations for springs has

been found to be at the base of high-standing thick Karoo dolerite sills intruded into the Karoo Supergroup sedimentary rocks in the interior, and the lower portions of slopes underlain by sandstone of the Natal Group in the coastal zone. Springs can also occur in lower slope and valley bottoms at differing rock type contacts, faults, joints, etc.

In recent years, a programme of spring protection has been implemented in a number of rural areas. Spring protection involves effectively covering and sealing the spring source and piping the groundwater under gravity to a storage tank down slope from where the water is tapped as required..

5.1.1 Seepages

Seepages with yields of the order of 200 l/h are also of widespread occurrence, especially in areas of higher rainfall. They are widely used in the rural areas as a source of domestic water supply. Seepage flows are even more markedly seasonal than springs, many drying up completely in the dry winter months, especially in years of below-average rainfall. Seepages are mostly shallow phenomena associated with perched water table conditions, the groundwater moving downslope and being perched in the base of sandy permeable topsoil overlying

relatively impermeable clayey subsoil or weathered rock. In areas underlain by Karoo Supergroup sedimentary rocks, lower slope seepages are frequently associated with, and give rise to ferricrete (laterite) occurrences, either within the soil profile or on the ground surface where exposed by erosion. Seepages are usually exploited by means of shallow pits in which the very small flow of groundwater accumulates, and from which it is drawn from time to time as required.

5.2 Thermal springs

The general temperature of groundwater is approximately 1 – 3.5°C above that of the average annual air temperature in the area of its occurrence (van Wyk, 1963). Thus groundwater temperatures in the map area vary from about 24.5°C in the Mkuze-Empanjeni coastal eastern portion to about 20.5°C around Dundee and Vryheid in the central west, and about 15°C at Wakkerstroom in the most elevated north western corner.

A number of true thermal springs, which have year-round

groundwater temperature in excess of 25°C occur in the map area. Details of the more important of these springs (Kent, 1950, 1969, 1981) are summarised in Table 6.

The Shushu thermal spring in the bed of the Tugela River, northeast of Kranskop, with a water temperature of 53°C is the third warmest spring in the country after Brandvlei near Worcester in the Western Cape, 64°C, and Tshipse in the Northern Province, 57°C

The groundwater of the Shushu thermal spring is more

Table 6. Thermal spring occurrences

NUMBER OF OCCURRENCE	LATITUDE & LONGITUDE	GROUNDWATER TEMPERATURE °C	ROCK TYPE	APPROXIMATE YIELD l/s
Sulphur Springs	27°11'S 31°06'E	31	Pongola Metasediments	6,3
Warmbad (Witrivier)	27°14'S 31°03'E	37	Granite-gneiss	0,9
Natal Spa	27°32'S 30°52'E	44	Granite-gneiss	3,5
Swartfolozi	28°02'S 32°18'E	41	Dwyka tillite over Granite	not known
Shushu (Tugela)	28°52'S 31°00'E	53	Gneiss and amphibolite	not known

saline (Total Dissolved Solids 1001 mg/l, pH 8.2) than that of the other 'Basement' rock thermal springs farther north, i.e. Natal Spa TDS 252 mg/l, pH 9.4; Warmbad TDS 210 mg/l, pH 8.7; and Sulphur Springs TDS 180 mg/l, pH 7.7. The Swart-foloji thermal spring groundwater is very saline having a TDS

of 2962 mg/l and pH 7.8. (Martinelli *et al*, 1994). As some of the spring names imply, hydrogen sulphide gas occurs dissolved in small amounts in some of the thermal waters. The thermal springs are usually associated with fracture or fault zones in the country rocks in which they occur.

5.3 Shallow hand-dug wells

Hand-dug wells have historically been used on the Maputaland Coastal Plain to reach the shallow groundwater table by the local rural people. In more modern times, precast concrete rings are sunk to stabilise the walls of the well. The wells com-

monly extend about two metres below the groundwater table and are only viable when they are less than 15 metres in depth. No database on the location or number of these types of wells currently exists.

5.4 Tube wells

A tube well is a hand augered borehole that penetrates unconsolidated sands. The depth of the well does not usually exceed 20 m. Commonly, 125 mm PVC pipe is used as casing material, of which the bottom three metres is slotted. A number of these

wells have been constructed on the Maputaland Coastal Plain and have proven to be successful in yielding up to 0.3 l/s. No records have been kept of the actual number of wells or their locations.

6 Groundwater development

6.1 Existing utilisation

The use of groundwater is constrained by the low yields (median 0,6 l/s) of boreholes drilled into secondary 'hard rock' aquifers, which underlie the majority of the map area. Larger yields (> 5 l/s) are obtained in a limited number of places from intergranular aquifers, as in the case of Mtubatuba's water supply which is drawn from a number of large-diameter screen well boreholes in the alluvium of the flood plain of the Mfolozi River. Another example is the augmentation of water supply for the dredge-pond mining operations of Richards Bay Minerals, which was obtained on demand from numerous screened boreholes in the coastal sediments. Similarly, the water supply for Nqutu is obtained from a system of screened caissons in the sandy bed of the Buffalo River at Vant's Drift, about 16 km away from Nqutu. A wellpoint type system is used to supply the village of Nondweni from the bed of the nearby Nondweni stream. The villages of Kranskop and Nkandhla obtain most of their water supply from fractured aquifer boreholes. A number of large industrial facilities in the map area either obtain all or augment their water supplies by the utilisation of groundwater. These include the Amatikulu and Mfolozi sugar mills in the coastal zone, and the paper and board mills at Piet Retief in the northwest interior. Some coal mines in the Utrecht area utilise groundwater inflow into their underground working for processing operations such as coal washing. Table 7 shows a summary of the major groundwater users.

Due to relatively low borehole yields, groundwater is not used to any significant extent for irrigated agriculture. Many farms and rural communities are, however, dependent upon groundwater boreholes for domestic and stock watering supply. A major constraint in rural water supply by means of groundwater has been the lack of provision of on-going maintenance of the borehole pumps used to extract the groundwater, particularly borehole hand pumps in the more remote rural areas. Over the higher rainfall portions of the sandy Maputaland Coastal Plain, shallow hand-dug wells are used extensively as the only source of domestic water supply.

It is estimated that total groundwater usage in the area covered by the Vryheid hydrogeological map sheet is currently some 60 million m³/yr. Current groundwater usage as a percentage of annual recharge varies from less than 1% on the Maputaland Coastal Plain and in some of the northern rural areas, to about 9% in the western interior river basin areas. Nowhere does the current groundwater abstraction rate approach that of the annual recharge to aquifers (average recharge of 5% of mean annual precipitation) covered by the map area. Scope therefore exists for further utilisation of the groundwater resources without detriment to the prevailing natural conditions, provided the resource is sensibly managed.

Table 7. Summary of major groundwater usage

LOCAL AUTHORITY	ABSTRACTION METHOD	TOTAL POTENTIAL ABSTRACTION
Nqutu	6m deep caissons in Buffalo River	170 l/s
Nondweni	6m deep wellpoints in Nondweni River	15 l/s
Mtubatuba	20 m deep screen wells on bank of Mfolozi River	100 l/s

6.2 Development potential

At present, the indications from aquifer recharge calculations, undertaken as part of the KwaZulu-Natal Hydrogeological Characterisation and Mapping Project are that the overall groundwater resource potential is about 39 000 m³/km²/yr. The resource potential, however, varies considerably within the map area. Thus in the case of the sandy intergranular aquifers of the Maputaland Coastal Plain, it varies from an estimated 205 000 m³/km²/yr in the high rainfall immediate coastal zone, to about 40 000 m³/km²/yr in the much drier zone along the Maputaland Coastal Plain inner margin, at the eastern foot of the Lebombo range. In the high rainfall plateau areas of the coastal hinterland that are underlain mainly by Natal Group sandstone, the groundwater resource potential is about 45 000 m³/km²/yr. In contrast, the much drier deeply incised river valley of the Tugela River which is underlain by acidic and basic metamorphic migmatite and granitic rocks

it is as low as 15 000 m³/km²/yr. In the interior river basins of the west that are underlain by Karoo sediments with intrusions of Karoo dolerite, the resource potential is about 22 000 m³/km²/yr, a similar value being applicable to the granitic Piet Retief area in the extreme northwest. Locally, the resource potential can be very much lower, in the order of only 5 000 m³/km²/yr where low rainfall and unfavourable hydrogeological conditions exist.

The main restraint on the utilisation of the resource, however, is the low groundwater yield of boreholes as a result of the generally unfavourable storativity and transmissivity characteristics of the fractured 'hard rock' aquifers which cover the greater portion of the map area. As a result, numerous boreholes are required to give limited amounts of water with resulting considerable costs for this type of water supply development.

Seymour and Seward (1996) have introduced the concept of a harvest potential. This term can be defined as the maximum annual volume of water, which is available for abstraction on a long term basis without exhausting the resource. To calculate the harvest potential, the recharge and groundwater storage were determined on a national scale. These two factors were further used to ascertain whether storage or recharge was the limiting factor for the purposes of calculating the harvest potential. Where recharge is a limiting factor, the size of the aquifer exceeds the annual recharge volume. This phenomenon typically controls the development potential of coastal and alluvial aquifers.

Areas where recharge is not consistent and where recharge has a marked impact on the development potential, aquifers are prone to drought. Where there is limited aquifer storage together with variable recharge, the harvest potential is limited by the storage capacity to bridge droughts. This condition is commonly found in the lower rainfall areas (< 500 mm/a) which are underlain by argillaceous Ecca and Beaufort Group rocks.

The third limiting factor is the available volume of effective storage. This means that even though there is enough recharge, the aquifer storage is not large enough to take in all the recharge water. The majority of the aquifers on the map sheet fall into this category. This is evident, in KwaZulu-Natal,

by the occurrence of many perennial streams, which are the recipient of water that cannot be contained in aquifer storage. Another additional constraint on the utilisation of groundwater is the low transmissivity of many of the aquifers. Both transmissivity and lack of aquifer storage are the most frequent limiting factors in developing the groundwater resource.

Other aspects to be considered in determining the development potential of groundwater are:

- Access for drilling equipment – many promising borehole locations are not accessible by regular drilling rigs. Much of the inland areas of the southern portion of the hydrogeological map have extremely high relief, which restricts the number of drilling sites available. Recent drilling programmes have, however, been improved by the use of earth moving equipment to push roads into areas that normally could not be accessed.
- Water quality can influence the suitability of the groundwater for use. Hydrochemical analysis should be carried out on all groundwater to establish whether concentrations of the various elements comply with SA Water Quality Guidelines (1993) for the intended use.

6.3 Borehole siting

Borehole siting is primarily concerned with the location of geological discontinuities, as higher borehole yields are generally associated with such features. Apart from direct geological observation, which is the most satisfactory method of borehole location where it can be practised, potential groundwater-bearing discontinuities can be located either by remote sensing methods or surface geophysical methods. In the case of the remote sensing methods, air photo interpretation has been used with considerable success, with satellite imagery not having been used to any significant extent as yet on account of its large perspective.

Geophysical methods are techniques that measure the physical properties of the earth's materials, such as density, electrical conductivity, magnetic susceptibility, electrical potential. Table 8 shows the recommended geophysical methods to use for the different rock types found on the Vryheid hydrogeological map.

Borehole siting in the unconsolidated sediments of the Maputaland Coastal Plain is not very successful with geophysical methods due to the difficulty in penetrating the thickness of the sands. It is best to use surface examination in order to delineate possible palaeochannels, which are expressed as gentle linear depressions on the ground, together with exploratory boreholes.

Table 8. Recommended geophysical methods to use in different rock types

LITHOLOGY	RECOMMENDED GEOPHYSICAL METHOD
Karoo argillaceous rock	EM, magnetics
Karoo arenaceous rock	EM, magnetics
Ecca Group shale resistivity,	EM
Vryheid Formation sandstone	EM, magnetics
Natal Metamorphic Province	resistivity profiling, magnetics
Dwyka Group diamictite	VLF, resistivity, FDM
Karoo dolerite magnetics,	EM
Natal Group sandstone	resistivity, EM
Letaba Formation basalt	EM, magnetics
Jozini Formation rhyolite	EM, magnetics

VLF = very low frequency electromagnetics

FDM = frequency domain electromagnetics (MAX-MIN)

6.4 Resource evaluation

After a borehole has been drilled, the groundwater resource needs to be evaluated in terms of the quantity it is likely to yield, and the quality of the water. Quantitative evaluation of the groundwater resource will be a deciding factor in determining the pumping rate the resource can sustainably deliver and is therefore one of the most important aspects of groundwater development. The amount of water that may be

abstracted from a borehole may be resolved by test pumping the borehole or by empirical methods i.e. by using the borehole over an extended period of time, monitoring the water-level response, and increasing or decreasing the yield until water-levels stabilize. Groundwater quality can only be determined by chemical and biological laboratory tests.

6.5 Groundwater management

Groundwater is "mined" or over-exploited when the amount of groundwater being abstracted exceeds recharge to the aquifer on a long term basis. This means that the groundwater level in boreholes will be drastically lowered, air inflow to a pump will occur and eventually the borehole will dry up, and even collapse. For proper management of an aquifer it is necessary to determine the storage capacity of the aquifer, in addition to estimating recharge, as well as any other inputs (e.g. effluent disposal, artificial recharge, stream baseflow) and outputs (e.g. springs flows, evapotranspiration), baseflow, and the position and abstraction rate of other boreholes.

The National Water Act (Act 36 of 1998) has initiated the concept of a reserve. The Act requires that the human and ecological reserve for all catchments must be determined before allocations on the remaining portion of water, including groundwater, can be made. This concept will ensure that there is enough water for basic human needs and the needs of the environment. The task of reserve determination is the responsibility of DWAF and must be seen as a tool through which the national groundwater resource can be equably managed.

On a different scale, it is up to the individual users of groundwater to ensure that over-abstraction does not occur in their boreholes. Users must adhere to initial recommendations made by the hydrogeologist and the following records on boreholes must be kept:

- water level measurements (weekly/monthly);
- recording of daily rainfall (if possible) and
- volume of water pumped (daily/weekly).

The above information can be used for long term management of the resource and for adjusting pumping rates to sustainable levels. This may include reducing the rate if a continuous declining trend in water levels is detected, or even increasing

abstraction rates if trends indicate the impact is limited.

It is important to note that the evaluation of sustainable yield and groundwater management options is a specialised task requiring the expertise of a professional hydrogeologist.

Apart from managing groundwater in terms of its quantity, it is very important to manage and protect its quality. Septic tanks, landfill sites, cemeteries, fertilisers, accidental chemical and hydrocarbon spills are all artificial sources of potential groundwater contamination. Contamination of an aquifer can also be caused if poorer quality groundwater is drawn into a borehole during pumping. This can be the case when coastal aquifers are overpumped, thus causing the landward migration of the freshwater salt-water interface. This is called salt-water intrusion.

Another issue, receiving attention in South Africa, is the effect of afforestation on groundwater. There have been reports of newly forested areas causing shallow springs, wetlands and even deeper boreholes to dry up. This is a conflict situation that needs careful consideration before permits for afforestation are granted. DWAF's Water Conservation campaign concentrating on the removal of alien vegetation is an example of successfully addressing the impacts on water resources.

The National Water Act outlines the government's responsibility for monitoring of water resources. Monitoring is a management tool that aims to obtain quantitative information on changes in groundwater storage, and changes in the physical, chemical and biological characteristics of the groundwater. A groundwater monitoring network, of dedicated boreholes throughout the province of KwaZulu-Natal, will be implemented. These boreholes will be used to monitor the ambient or background groundwater quality and levels for the various hydrogeological regions.

7 Recommendations for further studies

- i. The long-term monitoring of groundwater level behaviour and quality in representative or significant locations to confirm the recharge situation in relation to rainfall variation and borehole depth,
- ii. The investigation of the effect of intensive afforestation, especially by *Eucalyptus*, on the groundwater regime in portions of the region so affected,
- iii. Mapping and evaluation as a water resource the shallow wells on the Maputaland Coastal Plain,
- iv. Hydrogeological exploration of the Pongola Supergroup rocks,
- v. The effect on the groundwater regime of intensive urban or peri-urban informal settlement,
- vi. Exploratory hydrogeologic and stratigraphic borehole drilling, including deep boreholes (300 m), in specific target sites suggested by regional structural analysis, particularly extensional features, or other lithologic indications such as Karoo dolerite contact zones, faults and joints,
- vii. The investigation of the role of fracture density and orientation on groundwater occurrence and borehole yields,
- viii. The investigation of Karoo dolerite intrusions as targets for the siting of boreholes,
- ix. The investigation of the groundwater production potential of springs and their usefulness as sources of rural domestic water supply, and
- x. The investigation of the extent to which coal-mining operations have affected groundwater quality in proximity to existing and defunct mines.

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Appendix A. Health guides for drinking water

Source: Quality of Domestic Water Supplies. Volume 1: Assessment Guide. 2nd edition 1998. Water Research Commission No: TT 101/98. ISBN No: 1 86845 416 9

CONSTITUENT	CLASS 0 (Ideal)	CLASS I (Good)	CLASS II (Marginal)	CLASS III (Poor)	CLASS IV (Completely unacceptable)
Electrical conductivity (mS/m)	< 70	70 – 150	150 – 370	370 – 520	> 520
TDS (mg/l)	< 450	450 – 1000	1000 – 2400	2400 – 3400	> 3400
pH	5 – 9.5	4.5 – 5 9.5 – 10	4 – 4.5 10 – 10.5	3 – 4 10 – 11	> 3 > 11
Arsenic (mg/l)	< 0.01	0.01 – 0.05	0.05 – 0.2	0.2 – 2	> 2
Cadmium (mg/l)	< 0.003	0.003 – 0.005	0.005 – 0.02	0.02 – 0.05	> 0.05
Calcium (mg/l)	< 80	80 – 150	150 – 300	> 300	
Chloride (mg/l)	< 100	100 – 200	200 – 600	600 – 1200	> 1200
Copper (mg/l)	< 1	1 – 1.3	1.3 – 2	2 – 15	> 15
Fluoride (mg/l)	< 0.7	0.7 – 1	1 – 1.5	1.5 – 3.5	> 3.5
Iron (mg/l)	< 0.5	0.5 – 1	1 – 5	5 – 10	> 10
Total hardness as CaCO ₃ (mg/l)	< 200	200 – 300	300 – 600	> 600	
Magnesium (mg/l)	< 70	70 – 100	100 – 200	200 – 400	> 400
Manganese (mg/l)	< 0.4	1 – 0.4	4 – 4	4 – 10	> 10
Nitrate + nitrite (mg/l as N) or mg/l as NO ₃	< 6 < 26	6 – 10 26 – 44	10 – 20 44 – 89	20 – 40 89 – 177	> 40 > 177
Potassium (mg/l)	< 25	25 – 50	50 – 100	100 – 500	> 500
Sodium (mg/l)	< 100	100 – 200	200 – 400	400 – 1000	> 1000
Sulphate (mg/l)	< 200	200 – 400	400 – 600	600 – 1000	> 1000
Zinc (mg/l)	< 20	> 20			
Faecal coliforms (counts/100 ml)	0	0 – 1	1 – 10	10 – 100	> 100
Total coliforms (counts/100 ml)	0	0 – 10	10 – 100	100 – 1000	> 1000
Free available chlorine residual (mg/l)	0.3 – 0.6	0.2 – 0.3 0.8 – 1	0.1 – 0.2 0.8 – 1.0	0.005 – 0.1 1 – 1.5	< 0.05 > 1.5

